

Oct 1984

# Technical Report R-911

WHOI  
DOCUMENT  
COLLECTION

## XSP CONE PENETROMETER: A PERFORMANCE EVALUATION

By

R. M. Beard  
B. A. Johnson

October 1984

Sponsored by

NAVAL FACILITIES ENGINEERING COMMAND  
Alexandria, Virginia 22332

NAVAL CIVIL ENGINEERING LABORATORY  
Port Hueneme, California 93043

TA  
417  
N3  
no. R911



# METRIC CONVERSION FACTORS

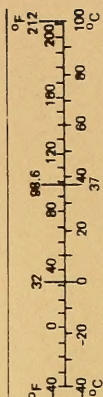
## Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
<b>LENGTH</b>				
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
<b>AREA</b>				
in <sup>2</sup>	square inches	6.5	square centimeters	cm <sup>2</sup>
ft <sup>2</sup>	square feet	0.09	square meters	m <sup>2</sup>
yd <sup>2</sup>	square yards	0.8	square meters	m <sup>2</sup>
mi <sup>2</sup>	square miles	2.6	square kilometers	km <sup>2</sup>
	acres	0.4	hectares	ha
<b>MASS (weight)</b>				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2,000 lb)	0.9	tonnes	t
<b>VOLUME</b>				
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft <sup>3</sup>	cubic feet	0.03	cubic meters	m <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.76	cubic meters	m <sup>3</sup>
<b>TEMPERATURE (exact)</b>				
°F	Fahrenheit temperature	5/9 after subtracting 32)	Celsius temperature	°C

\*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price \$2.25, SD Catalog No. C13.10.286.

## Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
<b>LENGTH</b>				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
<b>AREA</b>				
cm <sup>2</sup>	square centimeters	0.16	square inches	in <sup>2</sup>
m <sup>2</sup>	square meters	1.2	square yards	yd <sup>2</sup>
km <sup>2</sup>	square kilometers	0.4	square miles	mi <sup>2</sup>
ha	hectares (10,000 m <sup>2</sup> )	2.5	acres	
<b>MASS (weight)</b>				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1,000 kg)	1.1	short tons	
<b>VOLUME</b>				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m <sup>3</sup>	cubic meters	35	cubic feet	ft <sup>3</sup>
m <sup>3</sup>	cubic meters	1.3	cubic yards	yd <sup>3</sup>
<b>TEMPERATURE (exact)</b>				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TR-911	2. GOVT ACCESSION NO. DN787010	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) XSP CONE PENETROMETER: A PERFORMANCE EVALUATION		5. TYPE OF REPORT & PERIOD COVERED Not final; Mar 1980 — Jan 1983
7. AUTHOR(s) R. M. Beard and B. A. Johnson		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS NAVAL CIVIL ENGINEERING LABORATORY Port Hueneme, California 93043		8. CONTRACT OR GRANT NUMBER(s)
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Facilities Engineering Command Alexandria, Virginia 22332		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62759N; YF59.556.091.01.100
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE October 1984
		13. NUMBER OF PAGES 62
		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report)  Approved for public release; distribution unlimited.		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number)  Electric cone penetration, cone penetrometer, ocean bottom soils, seafloor geotechnical properties		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number)  A lightweight seafloor soil test device has been developed that is capable of performing in-situ cone penetration tests (CPT) to 40-foot sediment depth in up to 200-foot water depths. This device, called the XSP (experimental static penetrometer), weighs 10,000 pounds and stands 50 feet tall. The water-jetting system, a unique feature, assists pene- tration to greater depths than is possible with the 10,000-pound reaction force available.  continued		

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)





Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

20. Continued

The performance of the XSP has been evaluated in approximately 60 at-sea tests, and the penetrometer has proven reliable and produces repeatable data, which compare favorably with cores taken at the test sites. The water-jetting system aids penetration but does not affect the data. These XSP-supplied CPT data can be used to determine soil classification, relative density and friction angle in sand, and undrained shear strength in clay. They can also be used in the design of foundations (especially pile design) and in bearing capacity and settlement calculations.

Library Card

Naval Civil Engineering Laboratory  
XSP CONE PENETROMETER: A PERFORMANCE EVALUATION,  
by R. M. Beard and B. A. Johnson

TR-911 62 pp illus October 1984 Unclassified

1. Electric cone penetration 2. Cone penetrometer I. YF59.556.091.01.100

A lightweight seafloor soil test device has been developed that is capable of performing in-situ cone penetration tests (CPT) to 40-foot sediment depth in up to 200-foot water depths. This device, called the XSP (experimental static penetrometer), weighs 10,000 pounds and stands 50 feet tall. The water-jetting system, a unique feature, assists penetration to greater depths than is possible with the 10,000-pound reaction force available. The performance of the XSP has been evaluated in approximately 60 at-sea tests, and the penetrometer has proven reliable and produces repeatable data, which compare favorably with cores taken at the test sites. The water-jetting system aids penetration but does not affect the data. These XSP-supplied CPT data can be used to determine soil classification, relative density and friction angle in sand, and undrained shear strength in clay. They can also be used in the design of foundations (especially pile design) and in bearing capacity and settlement calculations.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

# CONTENTS

	Page
INTRODUCTION . . . . .	1
BACKGROUND . . . . .	1
CPT PRACTICE . . . . .	3
Data Interpretation . . . . .	3
Geotechnical Design . . . . .	4
APPROACH . . . . .	5
EQUIPMENT DESCRIPTION . . . . .	7
Structural Frame . . . . .	7
Cone Penetrometer . . . . .	7
Instrumentation Console . . . . .	9
Drive Mechanism . . . . .	12
Water-Jetting System . . . . .	12
EQUIPMENT OPERATION . . . . .	12
Deployment . . . . .	12
Operation . . . . .	13
Data Acquired . . . . .	16
TEST PROGRAM . . . . .	16
DATA REDUCTION . . . . .	19
TEST RESULTS . . . . .	19
Norton Sound, Alaska . . . . .	19
Port Hueneme, California . . . . .	26
San Francisco Bay, California . . . . .	27
Coronado, California . . . . .	33
DISCUSSION . . . . .	33
CONCLUSIONS . . . . .	38
RECOMMENDATIONS . . . . .	39
ACKNOWLEDGMENTS . . . . .	39
REFERENCES . . . . .	39
APPENDIX-INTERPRETATION AND USE OF CPT DATA . . . . .	42





## INTRODUCTION

This report describes the development of a seafloor soil test device capable of performing cone penetration tests to 40-foot sediment depths. The general objective of the project was to provide the Navy with a means of gathering geotechnical data on cohesionless soils to soil depths suitable for shallow piles and propellant anchors. The equipment developed was to be operable in water to 200 feet deep and suitable for operation from small anchored barges and other support vessels typical in Navy construction. The data provided from the electrical friction cone on the device was to be suitable for measuring soil strength and for soil classification.

Approximately 60 penetration tests were performed in various areas: in Norton Sound, Alaska; off Port Hueneme, Calif.; in San Francisco Bay, Calif.; and off Coronado, Calif. The data from some of these are presented in this report and data of this type can be directly applied to pile design using established methods. They are also suitable for selecting appropriate anchors and evaluating anchor performance. This development was funded by the Naval Facilities Engineering Command.

## BACKGROUND

The Navy is responsible for constructing a variety of facilities in the nearshore and continental shelf regions (i.e., in water depths to 1,000 feet). These include small to moderate-sized pile-supported platforms and pile-supported piers and elevated causeways, as well as various types of moorings incorporating pile, direct-embedded, or conventional drag-embedded anchors. Knowledge of geotechnical properties of cohesionless materials, correlatable to end-bearing-capacity factors, skin-friction-capacity factors, horizontal subgrade reaction moduli, and other data is required for the design of these facilities. For the majority of Navy situations, it is adequate to limit the soil depth of geotechnical property determination to 40 feet. This choice of depth was based on the depth of shallow piles used in Navy operations such as for the elevated causeway system (ELCAS) and the depth of embedment of propellant-embedment anchors.

At the initiation of this work, systems capable of measuring the required parameters and of reaching subbottom penetrations to 40 feet in sands required use of either (1) a borehole, (2) diver-operated or remotely operated heavy equipment, or (3) coring and property estimation. These systems are undesirable for Navy use for several reasons. For instance, the major disadvantages of making a borehole are that the process is time-consuming and expensive and requires special drill ships or at-sea platforms to complete the work.

For the second method, equipment that can perform cone penetration tests to 40 feet from bottom-resting platforms, are available but are very heavy -- 40,000 pounds; Seacalf and Stingray are two examples. Seacalf can operate independently of a drilling platform but requires a special handling system and heave compensators. Stingray is used to control a drill string and, therefore, is much like testing out of a borehole. Smaller bottom-resting equipment are available such as MITS (Multipurpose In-situ Testing System) but are not capable of 40-foot penetrations.

Coring of cohesionless soils to 40-foot soil depths is possible with vibracors weighing only a few tons. However, the highly disturbed samples are not suitable for measuring strength properties. Consequently, the properties must be guessed or estimated by rough rules of thumb which are less than desirable procedures and will not lead to confidence in a design.

To achieve a suitable way of evaluating cohesionless soils, the Naval Civil Engineering Laboratory (NCEL) first considered use of an instrumented vibracorer barrel to measure cohesionless sediment properties. A special instrumented barrel was fabricated that measured driving force, soil resistivity, and skin friction at several points along the barrel while taking a core. The idea was to use these in-situ measurements to control laboratory reconstitution of samples that would be extensively tested. Unfortunately, when the barrel was tested, the sensors were found to be easily damaged. Also, the data acquired were difficult to analyze (Lee, 1979). At this point, after a re-evaluation of candidate exploration techniques, it was decided that the use of established in-situ sensors was preferable even if a special bottom-resting platform needed to be developed to conduct the test (Lee, 1979).

Two possibilities existed: the standard penetration test (SPT) and the cone penetration test (CPT). The SPT is performed by dropping a 140-pound weight 30 inches (in air) onto a split-spoon sampler and counting the blows required to drive the spoon 1 foot into the bottom of a drilled hole after 6 inches of initial penetration. Because of the empirical nature of the SPT any change from this procedure negates the wealth of data that has been developed correlating blow count to soil properties. The SPT is designed to be performed in boreholes; therefore the objections that apply to drilling operations apply to the SPT.

The CPT, on the other hand, does not require a borehole. In this test, a cylindrical probe with a conical tip is pushed into the soil at a uniform rate of 0.02 m/sec or less. The probe is instrumented to measure the force on the tip of the cone and the friction on the side wall of the probe. The CPT provides detailed, continuous, and repeatable information on a site and is well-suited to solving many geotechnical design problems. Two disadvantages are that a large force is required to push the probe to desired depths, and no sample is obtained for inspection. However, the advantages outweighed the disadvantages, and the CPT was chosen as the testing device to be developed to satisfy the Navy's need for reliable data on cohesionless soils.



## CPT PRACTICE

The cone penetration test was first introduced in Europe about 50 years ago, but only in the last decade has its use in the United States become popular. Initial application was in design of piles. Increased sophistication of the CPT, particularly the development of the electrical-friction cone, has led to greater use of CPT-obtained data.

A recent advancement has been the piezocone, which measures pore water pressure response in addition to the mechanical response of the soil. Pore pressures are generated during penetration in the soil pore water that are recorded as part of the cone pressure. Being able to record this pore pressure and use it to make corrections during the analysis of CPT data are especially important in soft soils and offshore sands.

Interpretation of piezocone data is an active area of research. The presentation of CPT practice in this report is limited to the interpretation of electrical-friction cone data and the application of the data to geotechnical designs. Areas of interest are briefly discussed in terms of data interpretation and geotechnical design. As will be noted, interpretation and use of CPT data are different for sandy and clayey soils. Details of data interpretation and use of the data for design are presented in the Appendix.

### Data Interpretation

The data gathered during a CPT are the cone pressure and side friction. Values for these items are influenced by many variables, including soil type, density, fabric, and stress states, among others. No single unique theoretical relationship relates all the variables to the cone data, but theories have led to better understanding and interpretation of CPT data. However, empirical relationships are still the primary means of interpreting test results.

Soil Classification. Efforts to classify soils from CPT data were first reported by Begemann (1965). He found that the ratio of sleeve friction to cone pressure correlated well to median grain diameter. His findings have been confirmed and improved by other researchers (see Reference list). Today, soil classification charts are used widely to identify soil types, and these charts are being expanded to describe and classify problem soils, such as carbonates. These charts are dependent on cone type; a chart recommended by Martin and Douglas (1981) for electrical-friction cone is given in the Appendix.

Relative Density. Relative density of sands is estimated from cone pressure data. However, caution is warranted because the cone pressure data are affected by other factors such as overburden pressure. Recent research has shown that a much better interpretation of relative density can be made if at least one triaxial shear test is performed to define the relationship of relative density to friction angle for a particular soil. A graph of relative density as a function of cone pressure and overburden pressure (Schmertmann, 1978) is presented in the Appendix.

Friction Angle. Friction angle is proportional to relative density for a given sand. The Appendix presents two charts (Figures 27 and 28) for estimating friction angle. The one by Schmertmann (1978) uses relative density as an intermediate parameter to estimate friction angle as a function of soil type and relative density. The other (Mitchell et al., 1978) represents the practice in the Union of Soviet Socialist Republics and presents friction angle as a function of cone pressure and overburden pressure.

Undrained Shear Strength of Clay. The undrained strength of clay is back-calculated from the cone pressure by applying the bearing capacity equation. The difficulty lies in choosing an appropriate bearing capacity factor. The Appendix discusses this problem and provides guidance for selecting a bearing capacity factor.

Other Properties. The remolded strength, sensitivity, and overconsolidation of clays can also be estimated, but with less reliable results than undrained shear strength discussed in the preceding paragraph. Compression moduli for both clays and sand can be estimated. The determination of these properties is discussed in the Appendix, but the full development of the procedures is beyond the scope of this report.

### Geotechnical Design

Many different procedures have been developed for making geotechnical designs from CPT data. Each has its advantages, disadvantages, and a particular application where it is most suitable. Schmertmann (1978) prepared an extensive set of design guidelines for CPT data, and his work is often referenced. The procedures given in the Appendix have been extracted for the most part from Schmertmann's work.

Pile Design. Schmertmann recommends the "Dutch" procedure for estimating pile end bearing and the procedure of Nottingham (1975) for estimating side friction. These procedures are explained in the Appendix along with recommendations on how factors of safety should be applied to the results. The reader is also referred to Schmertmann (1978a) for methods used to analyze tapered piles, different shaped piles, and the effects of insertion methods.

Bearing Capacity. Bearing capacity in sand requires estimating bearing capacity factors from the CPT data and applying them to the Terzaghi bearing capacity equation. In clays, the cone pressure is used directly to estimate bearing capacity. The procedures and recommended factors of safety are given in the Appendix.

Settlement. Settlement calculations for footings on sand, with CPT data as the basis, are quite adequate. For footings over clays, the results are more uncertain. The procedure for making settlement estimates are not given in the Appendix because of their complexity and thus, exceed the scope of this report.



Pile Drivability. Drivability of piles has been correlated to cone pressure. One correlation was developed by DeRuiter and Beringen (1979) and is given in Appendix.

## APPROACH

After the decision to develop a platform for performing penetration tests was set, the operational requirements were set at 40 feet of penetration into uncemented sands, silts, and soft-to-medium clays at a maximum water depth of 200 feet. Forty feet of penetration in these soils was chosen because it was sufficient for designing the common shallow piles used in Navy operations (e.g., ELCAS) and would satisfy most of the requirements in propellant-embedded anchor work. The 200-foot water depth represented the design depth limit of many NCEL-developed shallow water systems, such as the Offshore Bulk Fuel System (OBFS), and therefore seemed to be a logical depth limit for this experimental device. Also, within this depth limit, difficulties in transmitting data and providing power to the device were minimized. Another requirement in the project was that the tool be operable from the type of Navy-owned vessel typically available. This vessel is usually a small barge with a deck-mounted crane. Also, this constraint in effect limited the weight of the tool to about 10,000 pounds.

The first step in developing this tool was to generate a conceptual design conforming to these operational limits. Woodward-Clyde Consultants (1980) was contracted to do the design. Their first thought was simply to extend the capabilities of an already developed cone penetrometer. However, it was apparent that the reaction required to push a cone 40 feet into sand would be about 30,000 pounds. This posed two problems. First, to provide the reaction by self-weight would violate a design provision; weight was limited to 10,000 pounds. Second, the rod used to push the cone would be susceptible to buckling under such loads. As alternatives to pure mechanical insertion of the cone, vibration and water-jet-assisted mechanical insertion were studied. Vibration was eliminated because of concern that the 40-foot penetration would not be obtained and that the cone's sensors would be damaged. The water-jet-assisted penetration appeared promising because there was experience in water jet penetrations to the necessary depth.

This concept was further developed by analyzing the hydraulics of jetting and the cone rod design. The configuration believed to be most viable was a vibracorer-type frame with a remotely controlled chain-driven, water-jet-assisted cone penetrometer (Figure 1).

The conceptual design of the device was moved to final design and fabrication by Fugro-Gulf, Inc. (1981). This device, called the XSP (for experimental static penetrometer), is the subject of this report. It is described in detail, operational procedures are presented, and the results of its evaluation are given. Procedures for interpreting CPT data and using it with geotechnical designs are given in the Appendix.

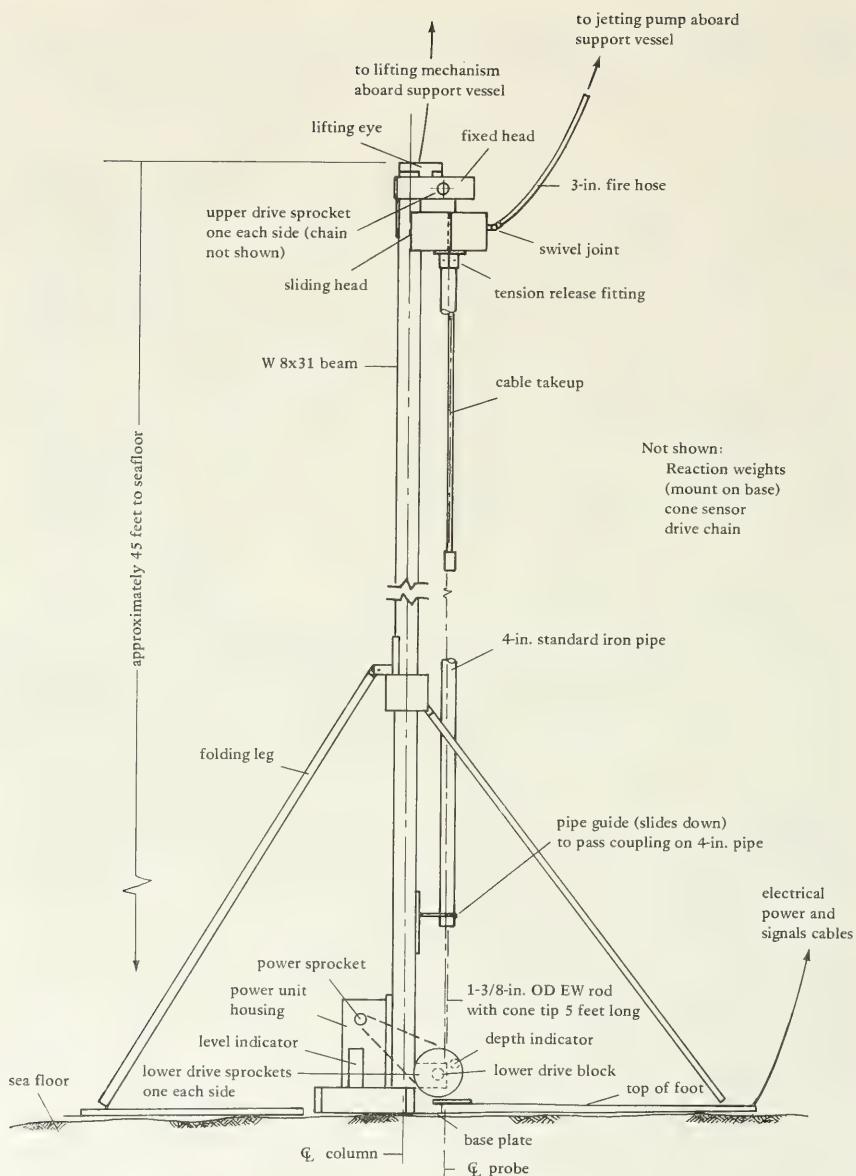


Figure 1. Conceptual design of a cone penetrometer with a 40-foot penetration capability.



## EQUIPMENT DESCRIPTION

The XSP (Figure 2) is a static cone penetrometer consisting of two major components: a 50-foot tall, 10,000-pound structure containing the cone penetrometer and an instrumentation console. In operation, the structure is set on the seafloor to perform a cone penetrometer sounding, while the instrumentation console located on the ship's deck is used to control and monitor the sounding and record the data. The data are later analyzed to determine soil characteristics and design parameters.

The structure is composed of a structural frame, a cone penetrometer, a drive mechanism for the cone penetrometer, and a water-jetting system for assisting penetration. The water jet is a feature not found on any other cone penetrometer. The structure's components and the instrumentation console are described in the following sections.

### Structural Frame

The steel structural frame (Figure 2) supports the cone penetrometer and provides a place to mount the motor and driving mechanism. This frame has three main structural parts: a square, table-like base; four support legs attached to the base with steel pins; and a tall, central H-beam bolted to the base. The base is approximately 4 ft<sup>2</sup> and 3 feet tall. Mounted on the top of the base are the electrical junction box to which all the electrical cables connect, the motor, and the gear box. On the bottom of the base is a space to add 1 ton of steel plate ballast. The legs are sturdy frames 4 feet wide and 8 feet long, pinned in place on the base. One of these legs is easily collapsed so it will fold up while pinned in place, allowing the structure to be either laid down on a ship's deck or hung close against the side of a ship. Since all four legs are similarly pinned to the base, this collapsible leg can be placed on any side of the base, depending on how the XSP will be placed on and deployed from the support vessel. All of the legs can also be unpinned at the top of the base and stretched out along the beam to make the structure more compact for shipping. The 20-foot span across the legs provide a stable base for the upright structure. The total bearing area provided by the bottom of the base and the pads on each leg is sufficient to support the structure on a very soft clay (about 0.5-psi shear strength). A central H-beam supports the push rods and parts of the rod's driving mechanism. The height of the H-beam can be changed to allow the XSP to operate in either a 40-foot or 20-foot soil penetration mode, in which the XSP stands 50 and 30 feet tall, respectively.

### Cone Penetrometer

The cone penetrometer (Figure 2) consists of two components: the push rods and the cone unit. The latter contains the electrical cone penetrometer tip. The push rods are 10-foot sections of Acker 2-1/4-inch OD AW flush-joint drill casing. Four push rods are used in the 40-foot mode and two in the 20-foot mode. The waterproof electrical cord to the cone unit runs inside the rods.

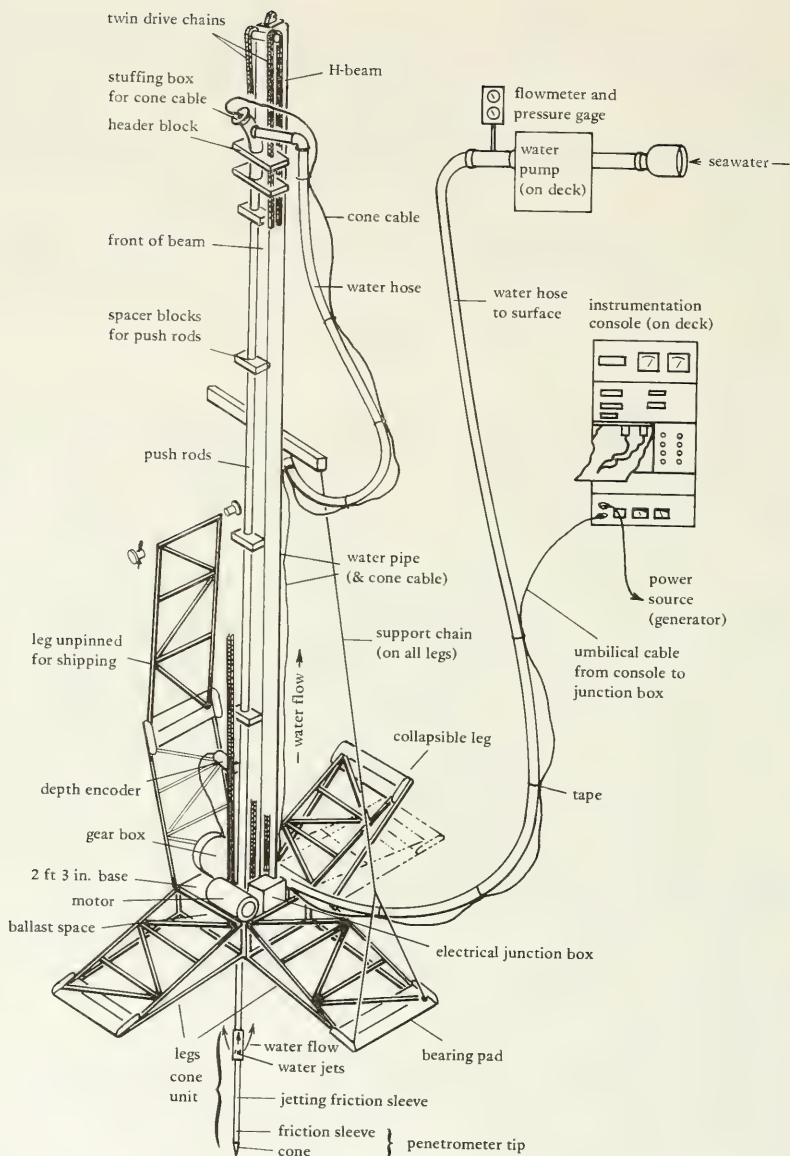


Figure 2. The XSP system.



Attached to the lower end of the push rods is the cone unit (Figure 3). The cone unit contains the jetting nozzle, upper sounding rod, jetting friction sleeve, lower sounding rod, and the electric penetrometer tip. This tip consists of a cone and a friction sleeve. The XSP penetrometer tip is a 5-ton Fugro Wilson Cone.

The jetting nozzle will be discussed in more detail in the section entitled Water Jetting System. Basically, water is pumped through the push rods and out the jetting nozzle. The water coming out the jetting nozzle is aimed back up the outside of the push rods to fluidize the soil and ease penetration of the push rods.

The upper sounding rod is a watertight structural connection between the jetting nozzle and jetting friction sleeve and it creates a separation between the waterjets and jetting friction sleeve. This sleeve is a strain-gaged section used to measure differences in the friction caused by the jetting water near the jets and the friction at the friction sleeve on the electric penetrometer tip.

The lower sounding rod is both a structural connection and separator between the jetting friction sleeve and the electric penetrometer tip. In the penetrometer tip, strain gages are used to measure pressure on the cone and friction on the sleeve 3 inches above the cone. The signals from the cone and the friction sleeve are amplified and transmitted up the cone cable and ultimately to the surface instrumentation console.

### Instrumentation Console

The instrumentation console (Figure 4) contains the controls for the XSP, monitors the sounding process, and records the data. This console, about 4 feet tall and 2 feet square, is housed in a fiberglass case. A power cable connects the console to a 208-volt, 3-phase AC, 30-ampere power source. The console is, in turn, connected to the junction box on the XSP's base by an underwater umbilical cable. From the junction box, cables lead to the motor, depth encoder, and the cone unit. The console also has readouts for two electronic pendulums located inside the junction box. The pendulums detect structure tilt in two vertical planes rotated 90 degrees from each other. Signals from these devices on the XSP are amplified and scaled for output to the panel meters and recorder. The major control on the console is an UP-STOP-DOWN switch for the driving mechanism and the cone penetrometer. There are digital readouts for the cone pressure, cone pressure and friction sleeve, friction sleeve, jetting friction sleeve, and depth of soil penetration. Electronically, the cone and friction are measured together and then the cone is subtracted to display the friction. Other gages provide readouts for the manually controlled 24-hour clock, tilt gages, a voltmeter, and an ammeter. The cone pressure, cone friction sleeve, and jetting friction sleeve are recorded on a Watanabe strip chart recorder as a function of depth.

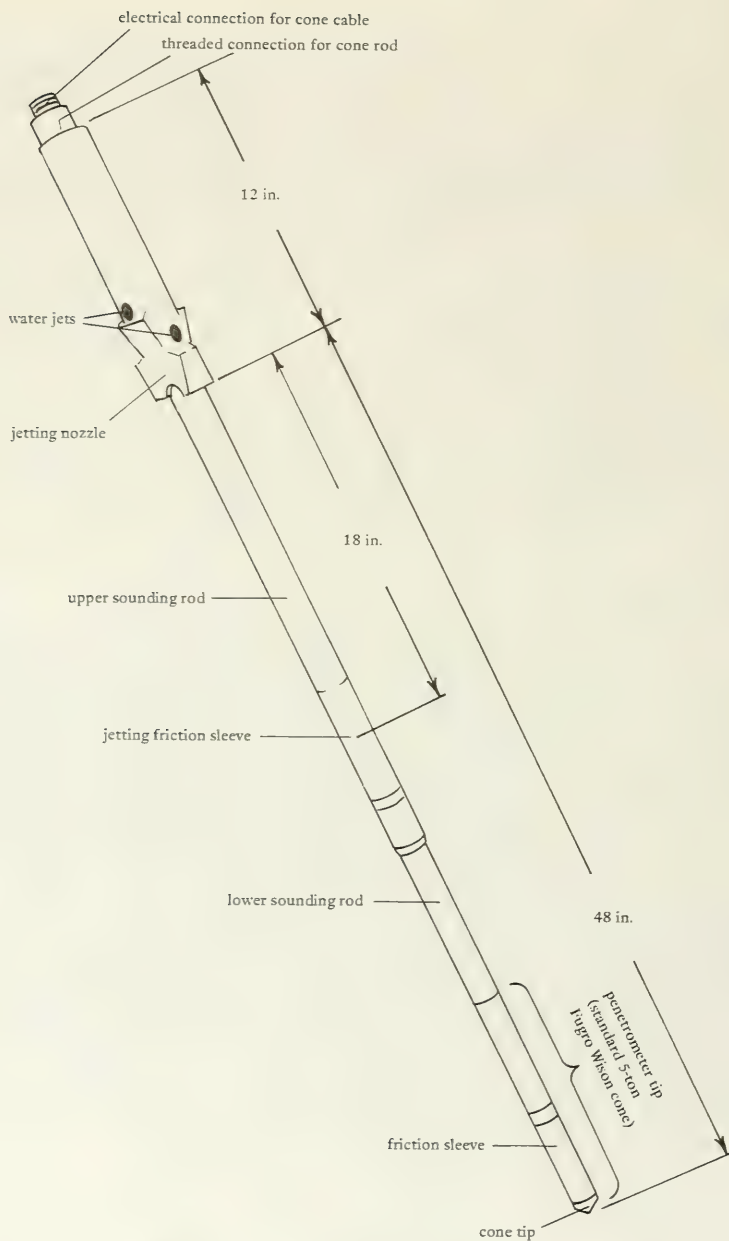


Figure 3. Cone unit of XSP.





Figure 4. Instrumentation console for XSP system.

## Drive Mechanism

The driving mechanism pushes the cone penetrometer into the seafloor. This mechanism is composed of a 1-hp motor and gearbox on the base, twin drive chains along the sides of the beam, and a guide track and bracing system for the push rods along the front of the beam (Figure 2). The drive chains are connected to a header block at the top of the push rods. The block slides along a track mounted on the front of the beam. The push rods are supported and guided along the track by spacer blocks. When the cone control switch is flipped to DOWN, the motor drives the chains which steadily push the header block and, consequently, the cone penetrometer downward. The depth of penetration is measured by a depth encoder on the side of the beam which is gear-driven by one of the drive chains.

## Water-Jetting System

The water-jetting system on the XSP is a unique feature. The jetting system consists of the jetting nozzle on the upper end of the cone unit, water hoses, and an on-deck water pump. The components are shown in Figure 2. Seawater is pumped through hoses to the header block, where it is directed down through the push rods and out and upward from the jetting nozzle. The purpose of the jetting is to fluidize the soil adjacent to the push rods to reduce soil friction and ease penetration. If too much water and pressure are used, the jetting can adversely affect the penetration data; this condition will be detected by a difference in the two friction sleeve readings. Experience has shown that 50 gpm at 50 psi does not influence the cone readings in a variety of mixed soils and sands. Jetting is not needed to achieve maximum penetration in most clays.

## EQUIPMENT OPERATION

To operate the XSP, the equipment must be assembled and the operating mechanisms checked out. After checkout the equipment is laid on the support vessel and transported to the location for the first sounding. The vessel is anchored or otherwise held stationary as the XSP structure is deployed and the cone penetrometer pushed into the soil while the console records the data. The process of inserting the cone penetrometer into the soil is often referred to as a sounding. The deployment, operating, and data acquired by the XSP are described in the following sections.

### Deployment

The XSP can be deployed in either of two ways: it can be stood up and deployed from the ship's deck with a crane, which depends on deck space and the type of lifting equipment available, or it can be deployed from a hanging position along the side of the vessel. To lay the XSP in the 40-foot mode down on the deck for transit to the test site, a triangular space 50 feet long with a 20-foot base must be available, along

with a crane capable of uprighting and lifting the 10,000-pound structure (Figure 5). The XSP in the 20-foot mode would need a 30-foot triangular space with a 20-foot base, and the structure weighs 8,000 pounds. Once the structure is uprighted, it can be lowered to the seafloor either by the crane (Figure 6) or switched to a lowering line off an A-frame.



Figure 5. XSP in 40-foot mode lying on deck of an LCU.

If the XSP cannot be deployed in this manner, then the structure can be hung horizontally from a pair of davits along the side of the support vessel (Figure 7). For deployment, the base is lowered from its davit until the structure is upright; then it is transferred to the lowering line and placed on the seafloor.

### Operation

At the sounding location, the support vessel must be anchored or otherwise held stationary during the sounding operation. Once the XSP structure is deployed and sitting on the seafloor, the water pump is started up to initiate the jetting system if it is to be used for the sounding, and the instrumentation is zeroed at the console.

If any slope to the seafloor exists, the initial position of the tilt-gage needles should be noted. The cone penetrometer is started down for a sounding, and its progress is monitored by observation of the strip chart recordings and the ammeter and tilt gages. A movement of either tilt gage indicates that the cone has met refusal. The cone penetrometer must be stopped immediately and retracted. Because the cone is no longer penetrating the soil, continued operation of the driving mechanism will cause the structure to crawl up the push rods. Eventually, the frame will tilt, and the cone unit and extended push rods will be broken off and lost.





Figure 6. XSP in the 40-foot mode being deployed by crane from deck of NCEL Ocean Research Craft (ORC).



Figure 7. XSP in the 20-foot mode being deployed from davits on the side of the support vessel.

When the sounding has been completed or refusal met, the cone is retracted. The structure can then be either moved over slightly to repeat the sounding for comparison or brought back on board before moving to a new sounding location.

#### Data Acquired

The data from the cone pressure, friction sleeve, and jetting friction sleeve for one sounding as recorded by the strip chart recorder are shown in Figure 8. Measurements are all recorded in kilograms per square centimeter. The magnitude of the chart scales can be varied for different soils by changing the millivolt settings on the strip chart recorder. The depth scale is dependent upon the chart speed, which can be set by chart controls or controlled by the depth encoder.

#### TEST PROGRAM

The testing of the XSP had two objectives. The primary one was to evaluate the jetting system in terms of its effectiveness in allowing deeper seafloor penetration and its effect on the data. A secondary objective was to perform a general evaluation by testing the penetrometer in different soil types. To meet these objectives field tests have been conducted with the XSP in Norton Sound, Alaska; near Port Hueneme, Calif.; in San Francisco Bay, Calif.; and near Coronado, Calif. The XSP test sites are shown in Figure 9.

The Norton Sound tests were conducted in conjunction with the U.S. Geological Survey (USGS). USGS's purpose in conducting these tests was to provide quantitative geotechnical information on the behavior of a variety of marine sediments that may be involved in processes (such as gas charging, wave-induced liquefaction, and ice gouging), potentially hazardous to offshore development. For the Navy, these tests provided an opportunity to evaluate the jetting system at a site with dense sands. The Port Hueneme tests were conducted to evaluate the jetting system in mixed soils (over 20% each of sand, silt, and clay) and to provide data to a project evaluating propellant-embedded anchor holding capacity. The XSP data can be used to calculate the undrained shear strength of the soil which is a parameter in the equation for propellant-embedded anchor holding capacity. The San Francisco Bay tests were conducted to evaluate the XSP in a "mud" seafloor and to provide additional data on the anchor holding capacity project. The Coronado tests were conducted to evaluate the water jet. The data were used by another project to determine the depth at which a layer of hard material, possibly cobbles, exists at this site.



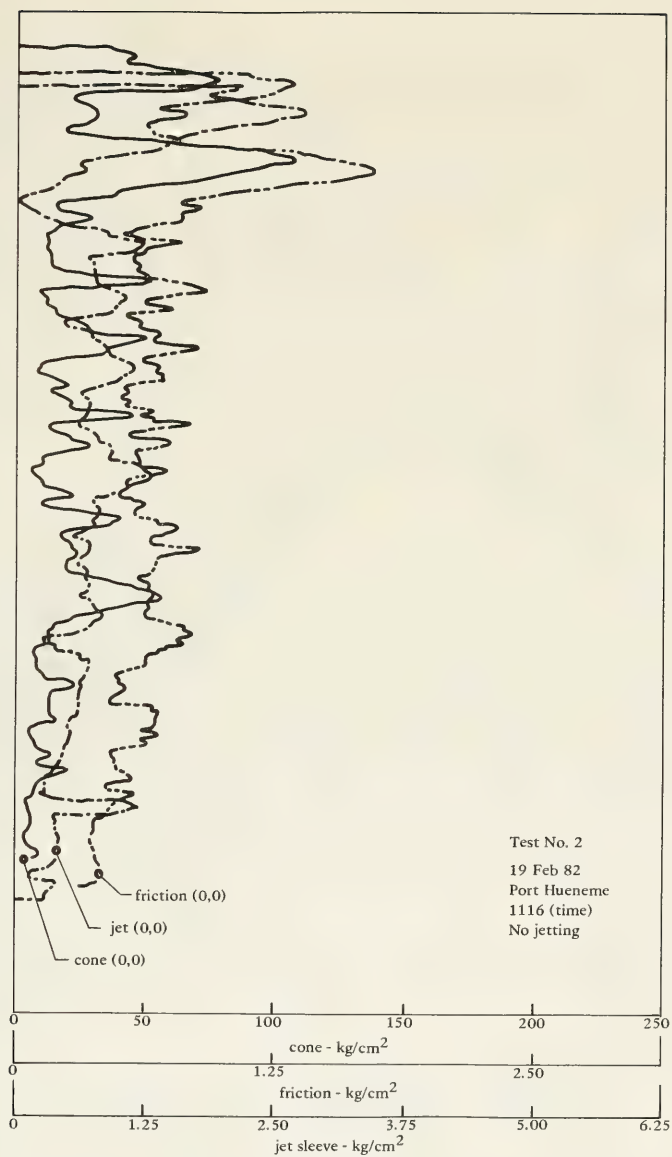


Figure 8. Strip chart recording of data from XSP instrumentation console.



Figure 9. Locations of XSP test sites.

## DATA REDUCTION

The data from the strip chart recordings (Figure 8) were digitized and used to calculate the friction ratio, which is the ratio between the sleeve friction and the cone pressure. This friction ratio is usually expressed as a percent. The cone pressure and friction ratio data were then plotted as a function of depth. Examples of these plots are given in Figures 10 and 11. Before forming the friction ratio, the sleeve friction and cone pressure readings were corrected to a common depth point by assuming that the measured cone pressure represents the behavior of sediment at the cone tip and that the friction stress represents behavior at the center of the friction sleeve which is 3 inches above the cone. Using these plots, soil profiles were developed over the depths of penetration using Figure 12 (a chart of soil type as a function of cone pressure and friction ratio). This chart was derived by Martin and Douglas (1981) for determining stratigraphy from data taken with electrical friction cover. Details on reducing the data are provided in the Appendix.

## TEST RESULTS

### Norton Sound, Alaska

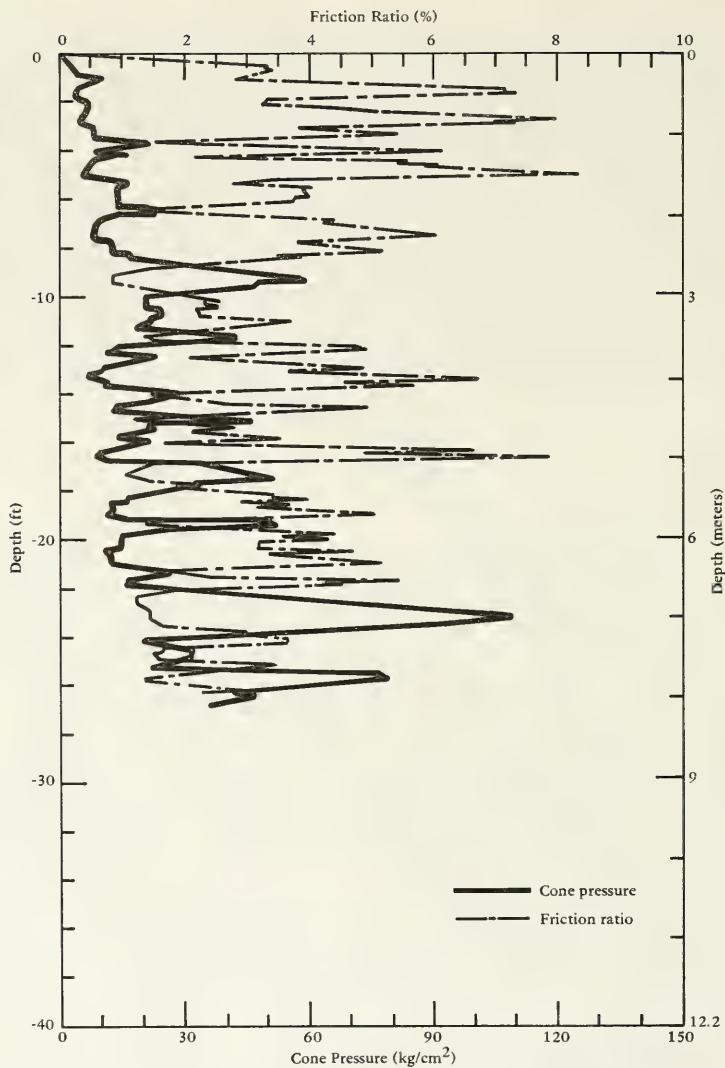
During the summer of 1981, a total of 40 soundings were made with the XSP in the 20-foot mode at the Norton Sound test site off the west coast of Alaska. National Oceanic and Atmospheric Administration's (NOAA) ship R/V DISCOVERER was used as the support vessel. In deployment from this ship, the XSP was hung horizontally over the side of the ship from a pair of davits (Figure 7).

All of the soundings were made without jetting because the cone unit with the jetting nozzle was broken off and lost on the first sounding. The backup cone (a penetrometer tip only) was fitted to the push rods and used to perform the remaining soundings. With this penetrometer tip, water jetting was not possible because the cone unit was not complete because it did not contain a jetting nozzle (see Figure 3). No problems were encountered while performing the remaining 39 soundings.

The soils encountered at the test site were very dense, limiting penetration to between 1.6 and 12 feet. Multiple soundings were made at most sounding locations, and the data were consistent between replicate soundings. Most of the sounding locations were also subsequently sampled with a vibratory corer and these cores compared well with the XSP data.

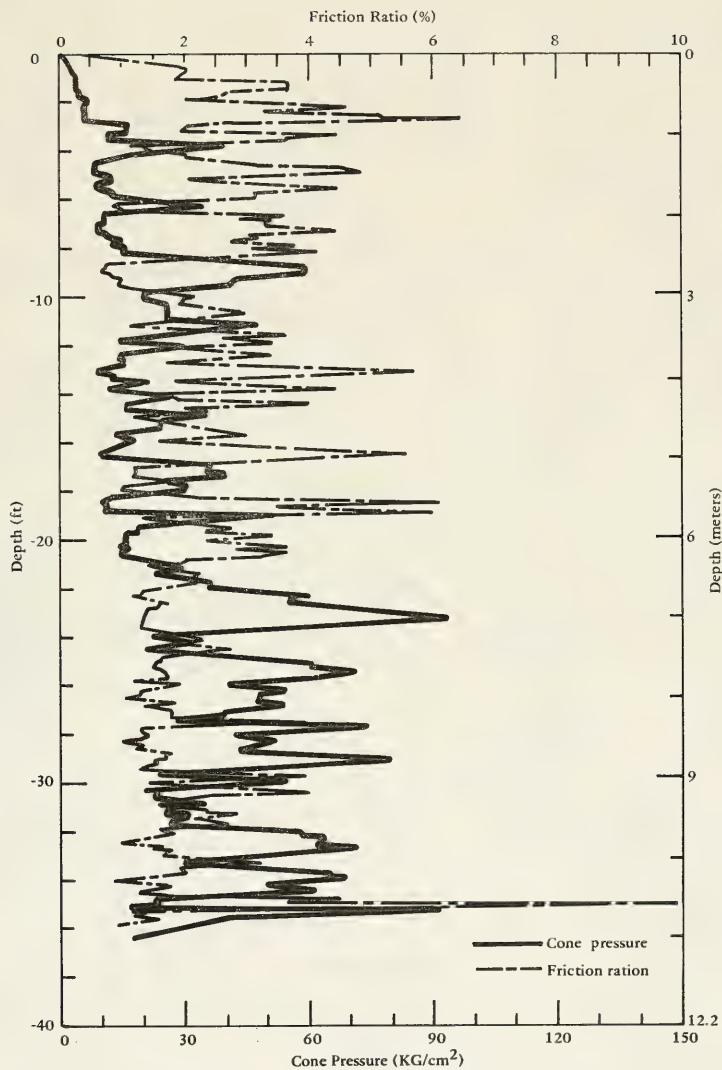
Within the test site, five areas were selected for the XSP soundings. These areas, shown in Figure 13a, were selected to provide coverage of the Norton Sound area and to cover in some detail areas that may be involved in processes potentially hazardous to offshore development. These potential geologic hazards -- gas charging, wave-induced liquefaction, and ice gouging -- were first detected by high resolution seismic profiling, side seam sonar, and geochemical and geological evaluation of soil cores. Reliable in-situ data were needed to quantitatively evaluate the hazard potential; thus the XSP was used.





Sounding 2: cone pressure and friction ratio (no jetting)

Figure 10. Plot of cone pressure and friction ratio versus depth for XSP sounding 2 done without using the jetting system offshore Port Hueneme.



Sounding 4: cone pressure and friction ratio (jetting)

Figure 11. Plot of cone pressure and friction ratio versus depth for XSP sounding done with the jetting system at the same location as the test shown in Figure 10.

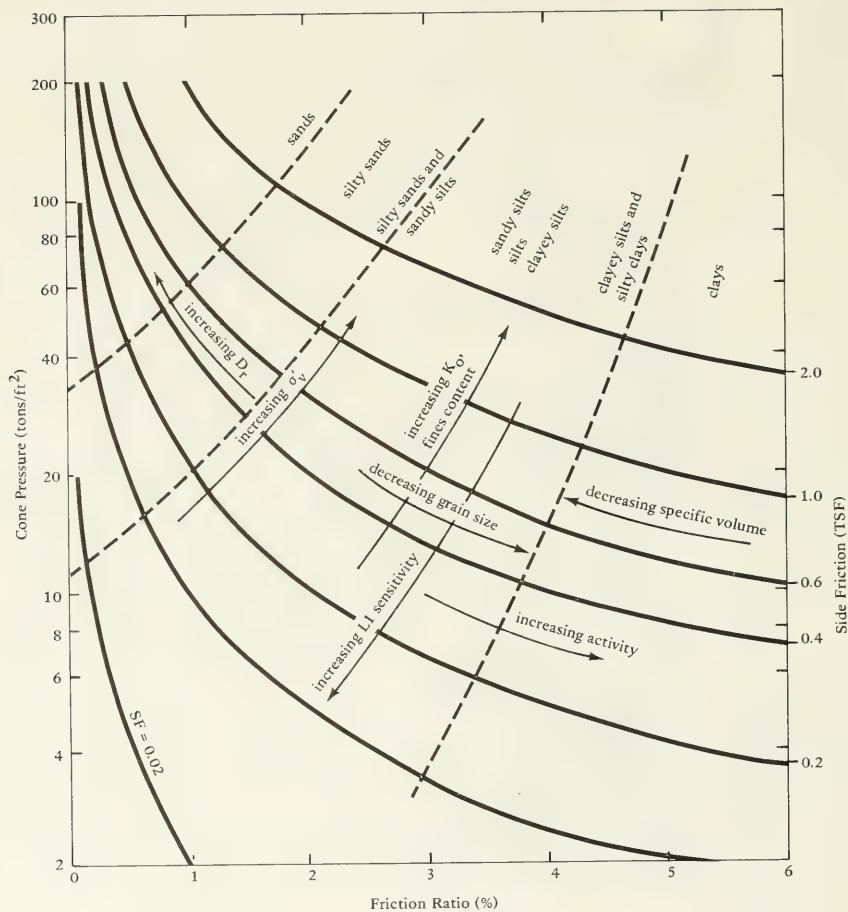
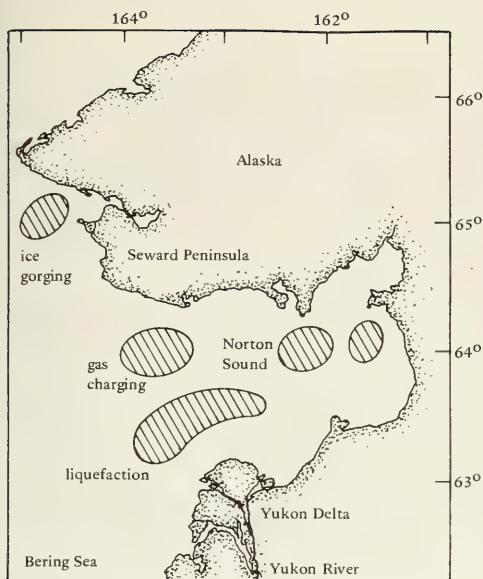
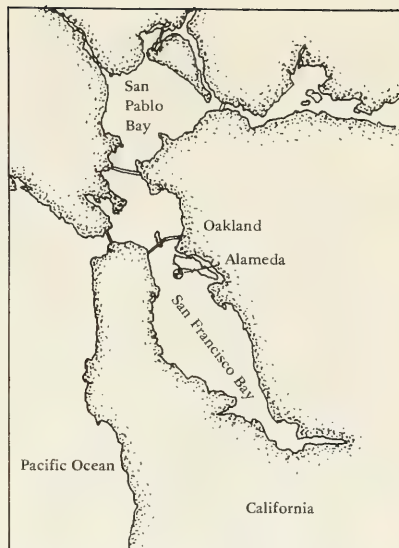


Figure 12. Classification chart for CPT data (Martin and Douglas, 1981).

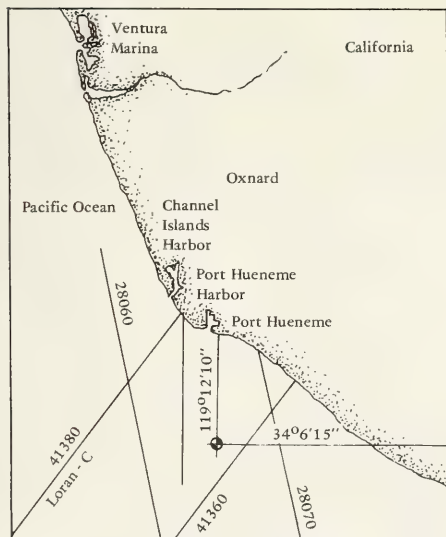




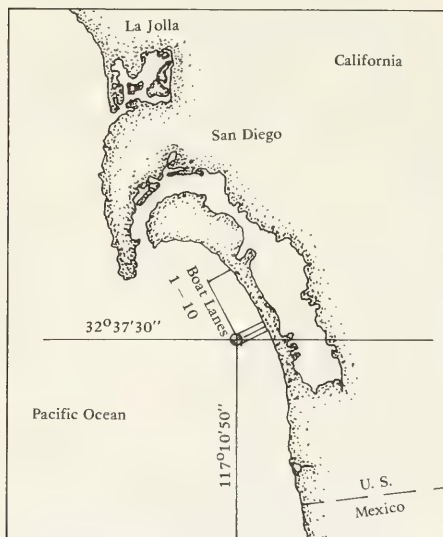
a. Norton Sound showing five sounding areas.



c. San Francisco Bay.



b. Port Hueneme.



d. Coronado.

Figure 13. XSP test sites.

Four of the 40 soundings (see Figure 14) will be discussed in more detail. The sounding plots are shown in Figure 15. The classification of the sediment from these four soundings is shown in Figure 16. These classifications agree reasonably well with classifications made on vibracore samples. The first sounding (Figure 15a) was within an acoustically identified gas-charged sediment. Low strength sediments due to gas charging may be more vulnerable to scour and storm-wave-induced shearing stresses. The second (Figure 15b) was 0.6 miles west of the first and just out of the gas-charged sediment area. The drops in cone pressure seen in Figure 15a corresponded with gas-charged zones in the sediment identified from vibracores. The slight difference between the peak envelopes of cone pressure in Figures 15a and 15b may be a result of somewhat lower effective stresses in the lighter gas-charged material. The soundings shown in Figures 15c and 15d are from the Yukon prodelta area. The Yukon prodelta contains sediment that is in the fine sand to silt range which is often associated with liquefaction due to cyclic loading on shore. Storm waves propagating northward from the Bering Sea generate large cyclic bottom shearing stresses in Norton Sound. This could result in liquefaction and movement of large sheets of sediment within this area. The first sounding (Figure 15c) is from a more protected area to the northwest and the second (Figure 15d) from an area on the west side that is more exposed to intense storm activity. It is apparent that the sediment in the protected area is not as dense as the sediment in the exposed area (Figure 15d).

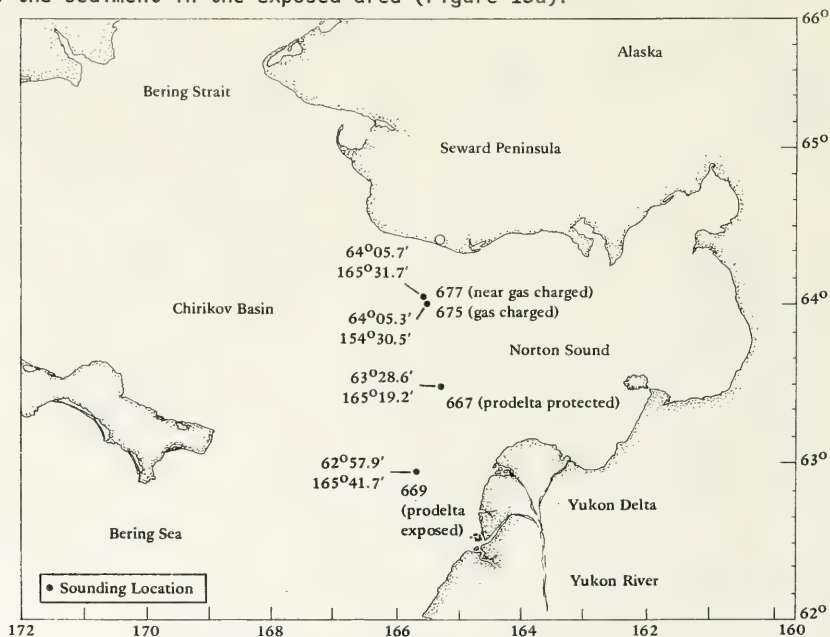
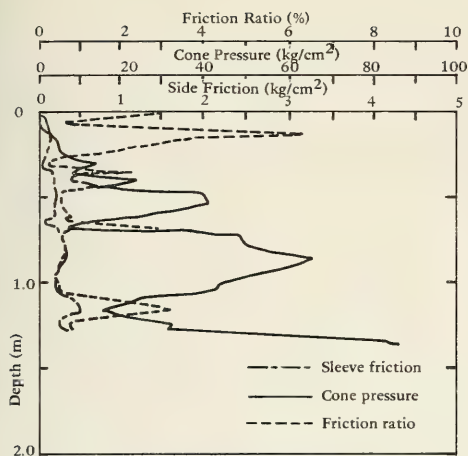
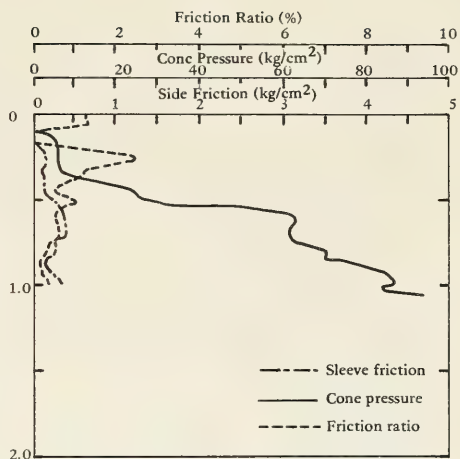


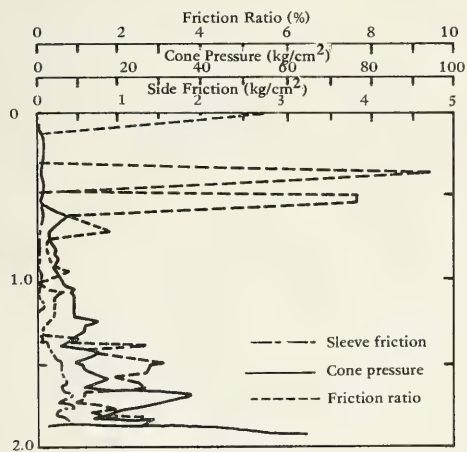
Figure 14. Four of Norton Sound's sounding locations.



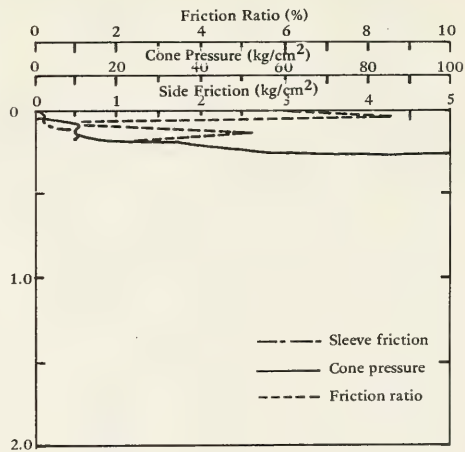
a. Sounding records for site 675 (gas charged sediment).



b. Sounding records for site 677 (near gas charged area).



c. Sounding records for site 667 (Yukon prodelta, protected).



d. Sounding records for site 669 (Yukon prodelta, exposed).

Figure 15. Example XSP sounding records from Norton Sound for the four soundings.



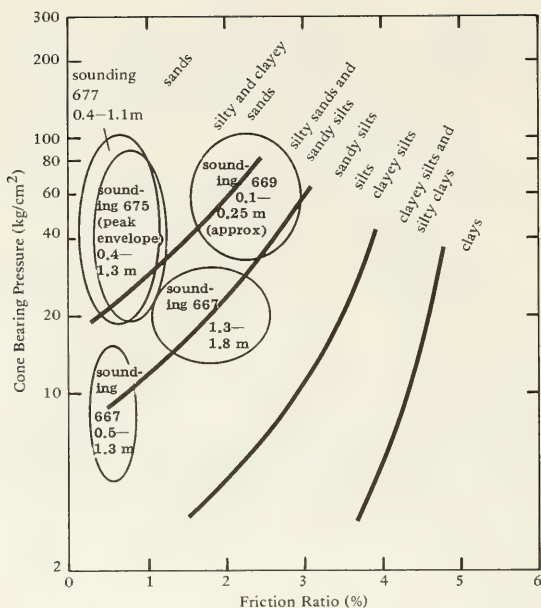


Figure 16. Correlation of friction ratio, cone pressure, and sediment type for the four soundings at Norton Sound.

### Port Hueneme, California

The XSP was tested at a site offshore Port Hueneme in February 1982. The purpose of the testing was to evaluate the XSP and its water-jetting system in a mixed seafloor and to provide data for an anchor holding capacity project.

Six soundings were conducted with the XSP in the 40-foot mode at the site offshore from Port Hueneme (Figure 13b). A detailed map of the sounding locations given in LORAN-C coordinates is shown in Figure 17. The NCEL Ocean Research Craft (ORC) (warping tug) was used as the support vessel. The XSP was deployed using a crane and lowered to the seafloor from the A-frame with a line.

One minor problem with the XSP occurred in conducting this test. The jetting sleeve malfunctioned at the beginning of the testing. Side-by-side soundings (with and without jetting) were done for comparison of the effect of jetting on the cone data. Soundings 1, 3, and 4 were conducted with jetting at a water flow rate of about 50 gpm and a pressure of 50 psi; soundings 2, 5, and 6 were done with no jetting. Examples of reduced sounding data from this location are shown in Figures 10 and 11. Figure 10 is sounding 2 where the water jet was not used and Figure 11 is sounding 4 where the water jet was used. These two soundings were separated by about 100 feet. It should be noted that 10 more feet of penetration was achieved when the water jet was used. The data were consistent between soundings, proving the XSP is capable of providing reproducible data. Stratigraphy developed from each of the six soundings is shown in Figure 18.

Two cores were taken with an Alpine Vibracore at the LORAN-C sounding locations of both soundings 1 and 2. The stratigraphy developed from the core data is shown in Figure 19 as is the stratigraphy developed from soundings 1 and 2. The stratigraphy from sounding 1 compares favorably with the stratigraphy from cores 1 and 2 taken nearby. The same good comparison is found between cores 3 and 4 and nearby sounding 2. This again shows that the XSP provides reliable data.

#### San Francisco Bay, California

The XSP was tested at a site in San Francisco Bay (Figure 13a) on 16 June 1982. This testing was to evaluate the XSP in a silty-clayey (usually called a "mud") seafloor and to provide supporting soil data for an anchor holding capacity project.

Three soundings were conducted with the XSP in the 40-foot mode using an LCU as the support vessel. The LCU-1466 was provided by the 481st Transportation Company (Heavy Boat) of the U.S. Army Reserves. The XSP was handled with a crane loaded on the LCU and tied down to the deck. The XSP was laid down on deck with the top end hanging out over the bow (Figure 5). The locations of the soundings are shown in Figure 20. Exact coordinates for sounding locations of soundings 1 through 3 are not known because navigation equipment was not available.

The first sounding reached a subbottom depth of 29 feet, and the second sounding reached 38 feet. The third sounding was terminated at 20 feet because the increasing current was causing the ship to drift away from the structure which made it increasingly difficult to retrieve the structure. The data from these soundings showed the soil to be a very soft silty clay to clayey silt. The overburden pressure was subtracted\* from the cone pressure in the analysis of these data. The data from the second sounding is shown in Figure 21.

No problems were encountered in using the XSP, except for the ship's inability to maintain station.

---

\*If it is not subtracted, it changes the soil classification to an incorrect classification.

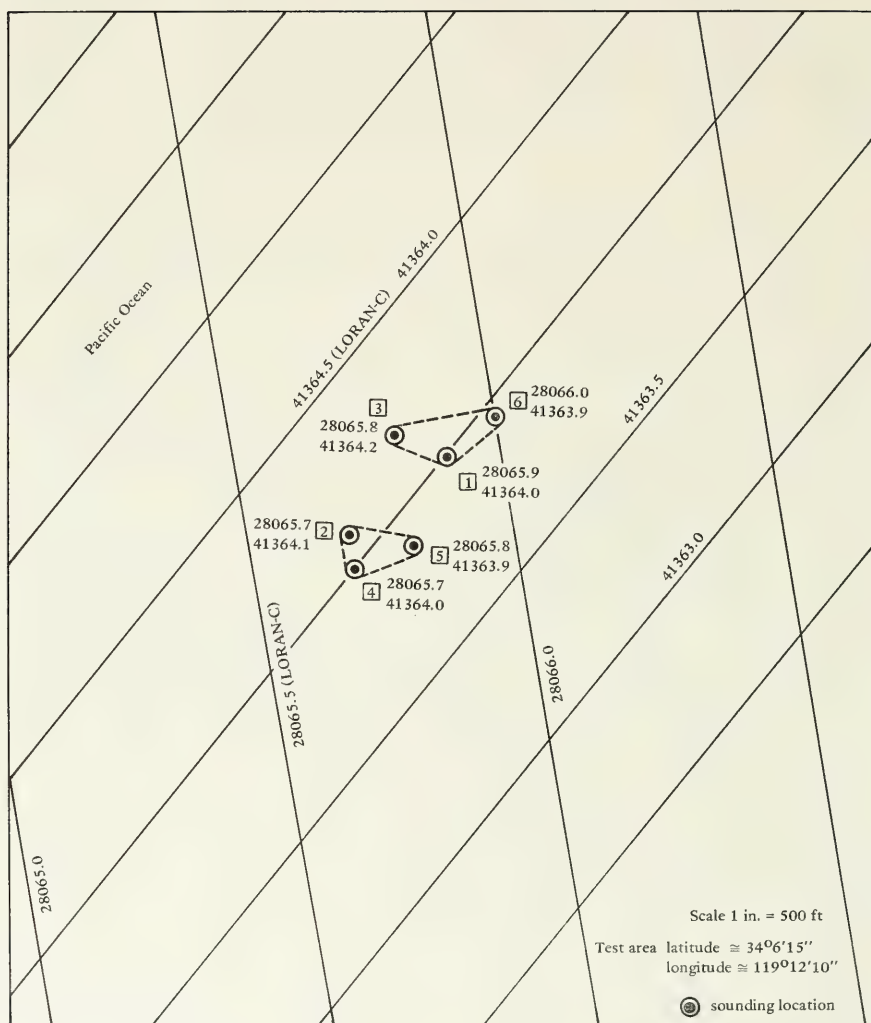


Figure 17. Port Hueneme test site for the XSP in the 40-foot mode on 19 February 1982, showing six sounding locations given in LORAN-C coordinates.



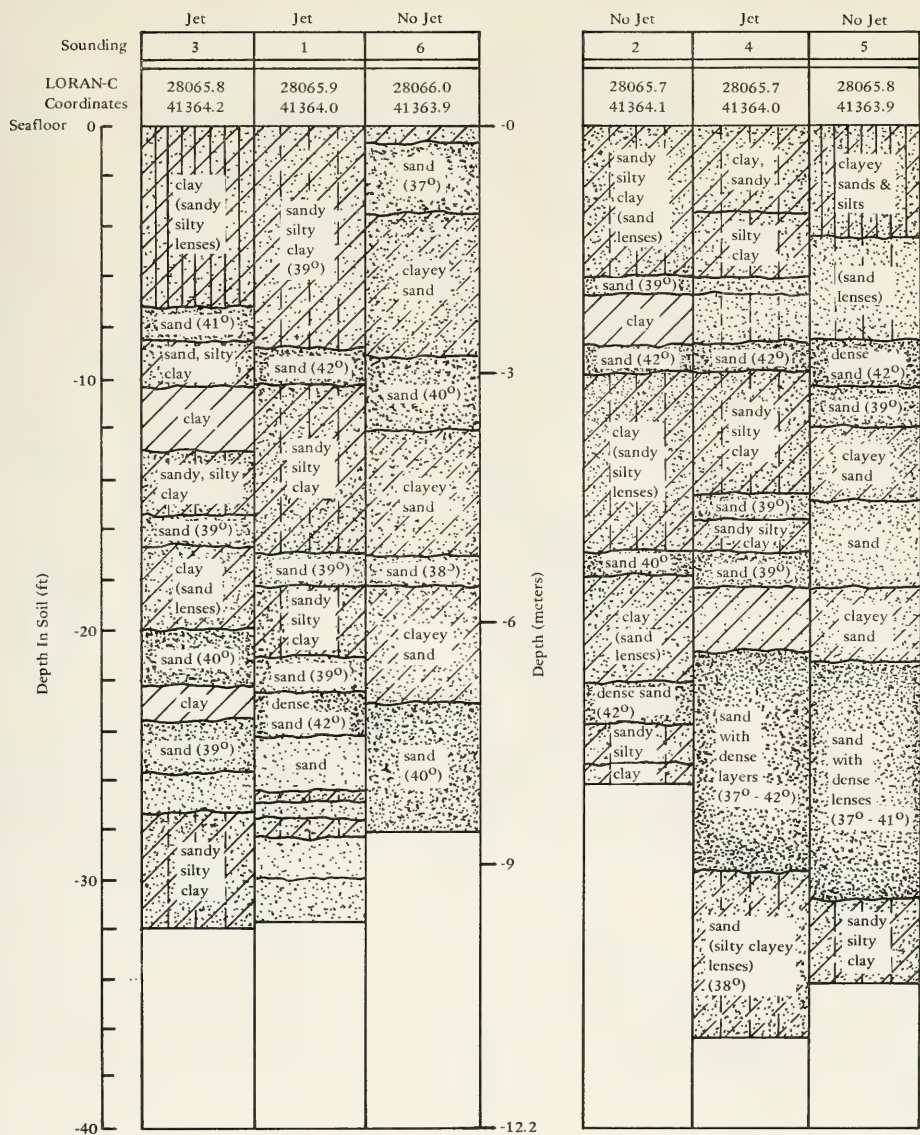


Figure 18. Stratigraphy test site developed from XSP data taken at Port Hueneme on 19 February 1982.

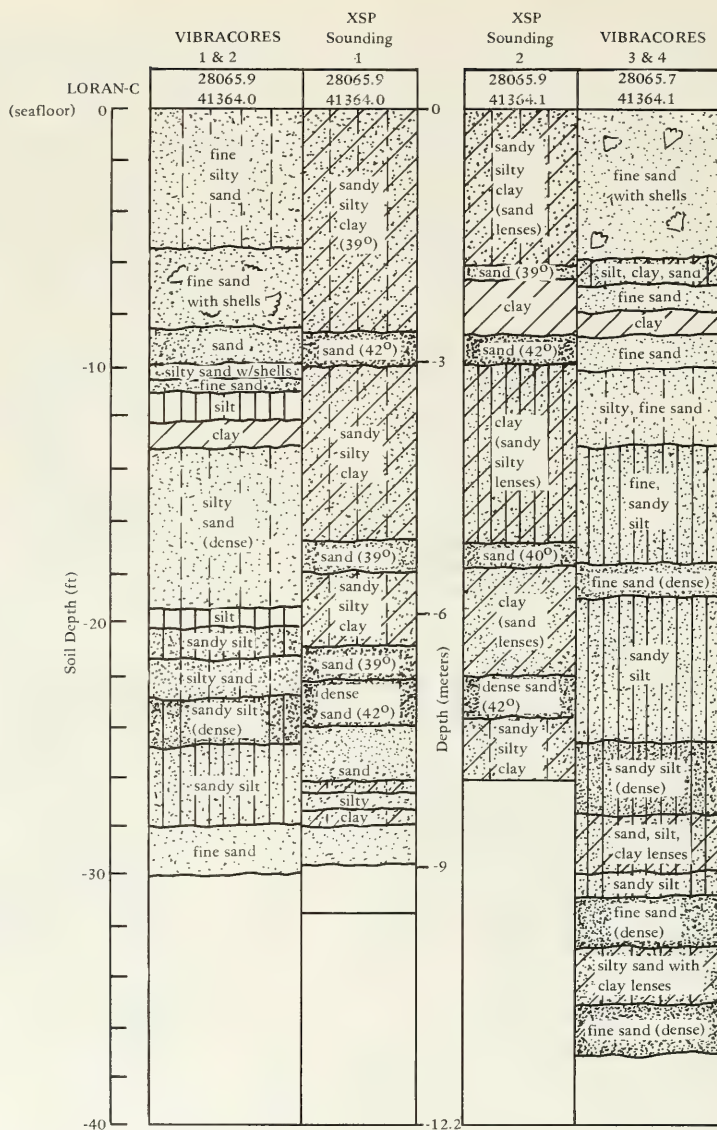


Figure 19. Vibracore stratigraphy from Port Hueneme test site compared to sounding stratigraphy from the same location.

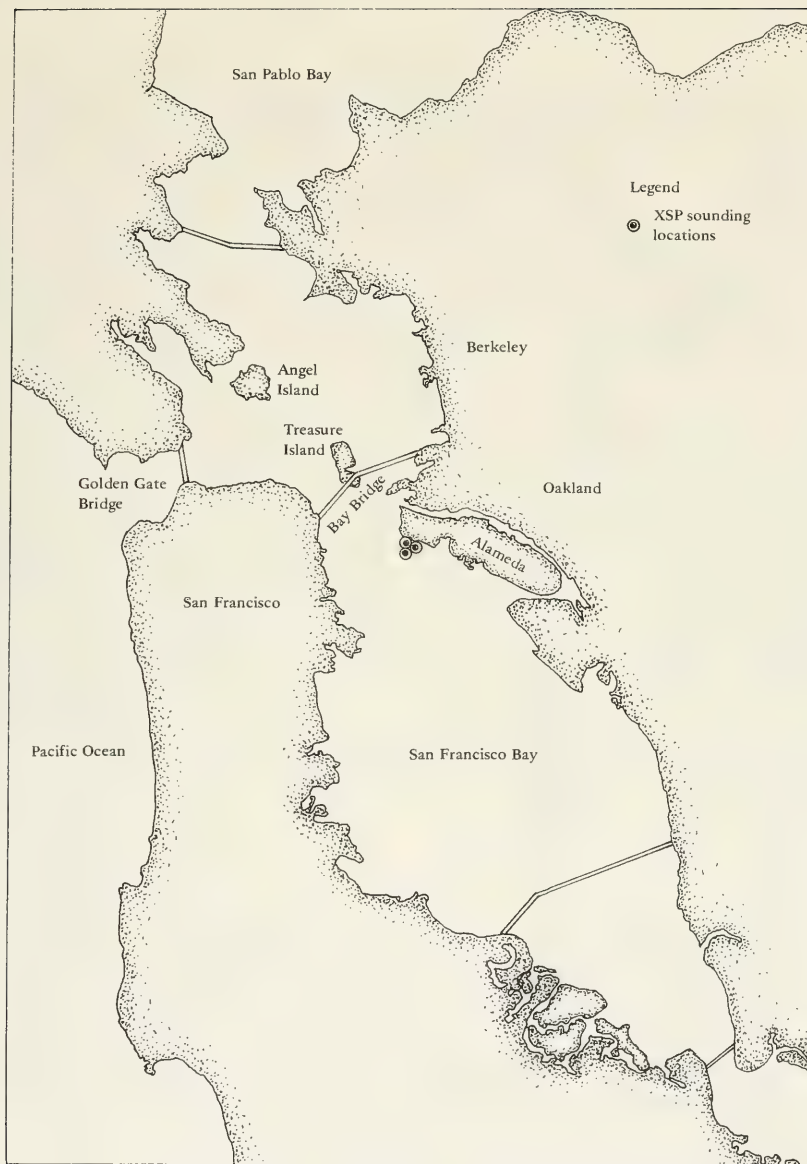


Figure 20. San Francisco Bay XSP test site, 40-foot mode, 16 June 1982.

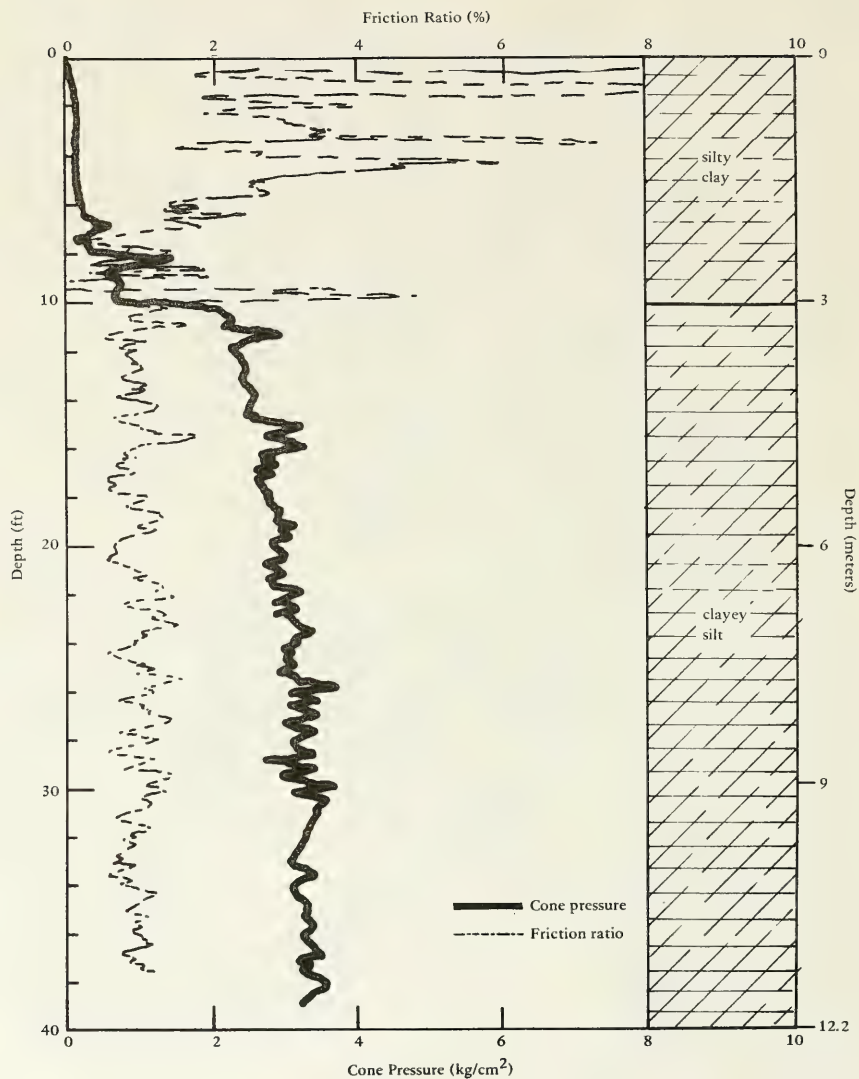


Figure 21. Cone pressure and friction ratio for XSP sounding 2 in San Francisco Bay.



## Coronado, California

The XSP was tested at a site offshore from Coronado, Calif. (Figure 13d). A total of 15 soundings were made with the XSP in the 20-foot mode on 31 October 1982. The XSP was deployed from the deck of the NCEL Ocean Research Craft (ORC) (warping tug) with the crane (Figure 6). This site was used by the Offshore Bulk Fuel Supply (OBFS) to install a Single Point Mooring (SPM) buoy using four large drag-embedment anchors. The locations of these anchors were marked with bouys (Figure 22) and labeled North, South, East, and West. Three XSP soundings were conducted at each of the four anchor marker bouys; two of the three used jetting at a water flow rate of 50 gpm and a pressure of 50 psi. Three other soundings (numbers 13, 14, and 15) were taken in the area probing for the cobble layer detected with a jet probe in February 1981. The data were very consistent from sounding to sounding. An example is provided in Figure 23. The stratigraphy developed from the 15 soundings is shown in Figure 24. Those soundings conducted without jetting reached 7 to 8 feet in depth. For three of the sites, the soundings with jetting reached from 8-3/4 to 9-1/2 feet in depth. At the East Buoy, however, refusal was met on one sounding at 5-1/4 feet with jetting and at 7-1/2 feet for the remaining two soundings (one with and one without jetting). Refusal may have been met at 5-1/4 feet due to hitting a cobble layer or rock since, at the end of the testing, the cone tip was found to be flattened. The last three soundings were done to probe and map the area. One sounding was shoreward of the bouys where refusal was met at 6-1/2 feet, and the other two were seaward of the bouys where refusal was met at 9-1/2 feet. The results of these soundings are similar to those of jet probing done at the same sites (Figure 25).

No problems were encountered in conducting these soundings. However, it is apparent that very dense sands or cobble layers cannot be penetrated with the 10,000 pounds of thrust which can be developed by the XSP.

## DISCUSSION

In general, the XSP has shown itself to be a reliable piece of equipment for gathering in-situ soil data. A total of 64 soundings were performed, and the only major problem encountered was on the very first sounding when the cone unit was broken off and lost. The XSP can be handled easily if the support vessel has the proper amount of space and lifting equipment. The easiest way to deploy the XSP is with a deck crane (Figure 6). However, it was demonstrated during the tests at Norton Sound that the XSP can be deployed from a horizontal position when held by davits over the side of the ship (Figure 7). Successful deployment and recovery of the XSP requires a stationary support vessel. Deployment has been made in sea state 2, and it is anticipated that sea state 3 is a limiting condition (depending on the support vessel and handling procedures).

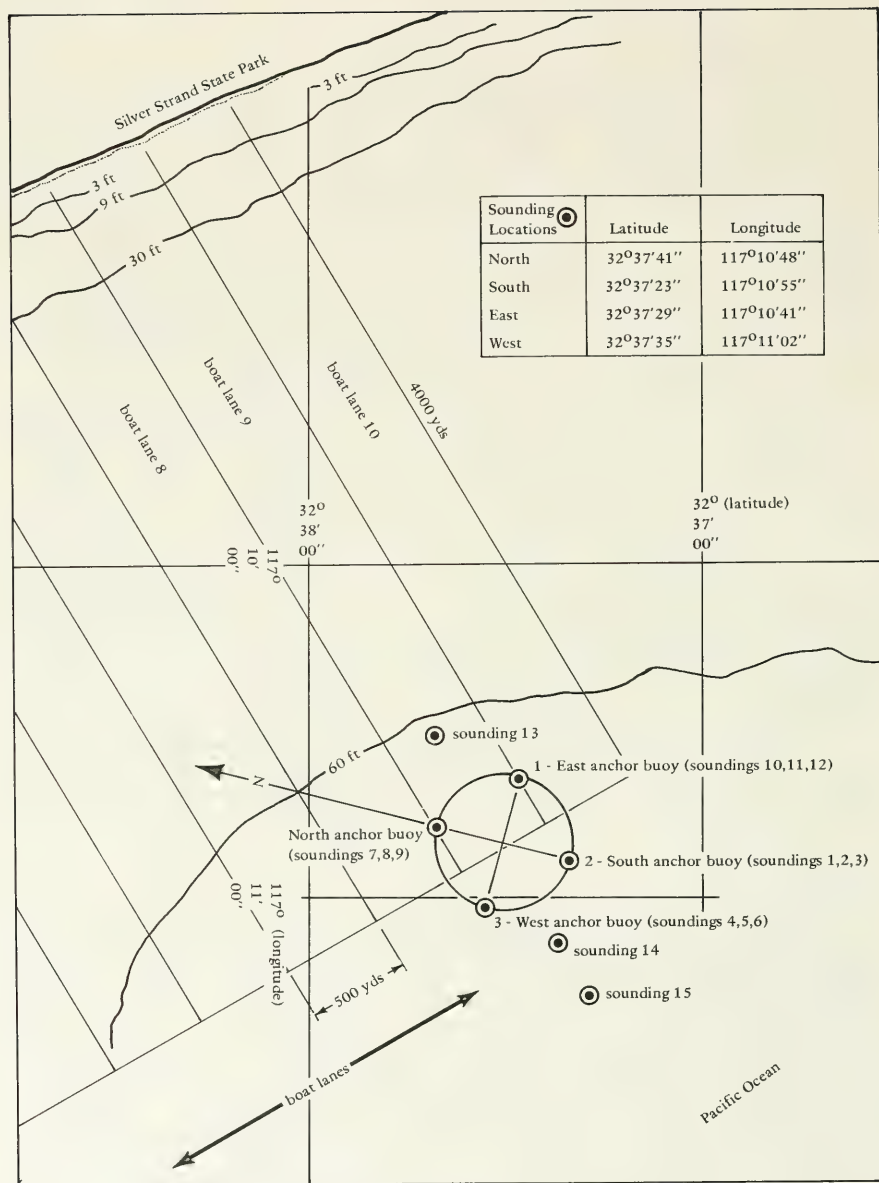


Figure 22. Coronado XSP test site, 20-foot mode, 31 October 1982.

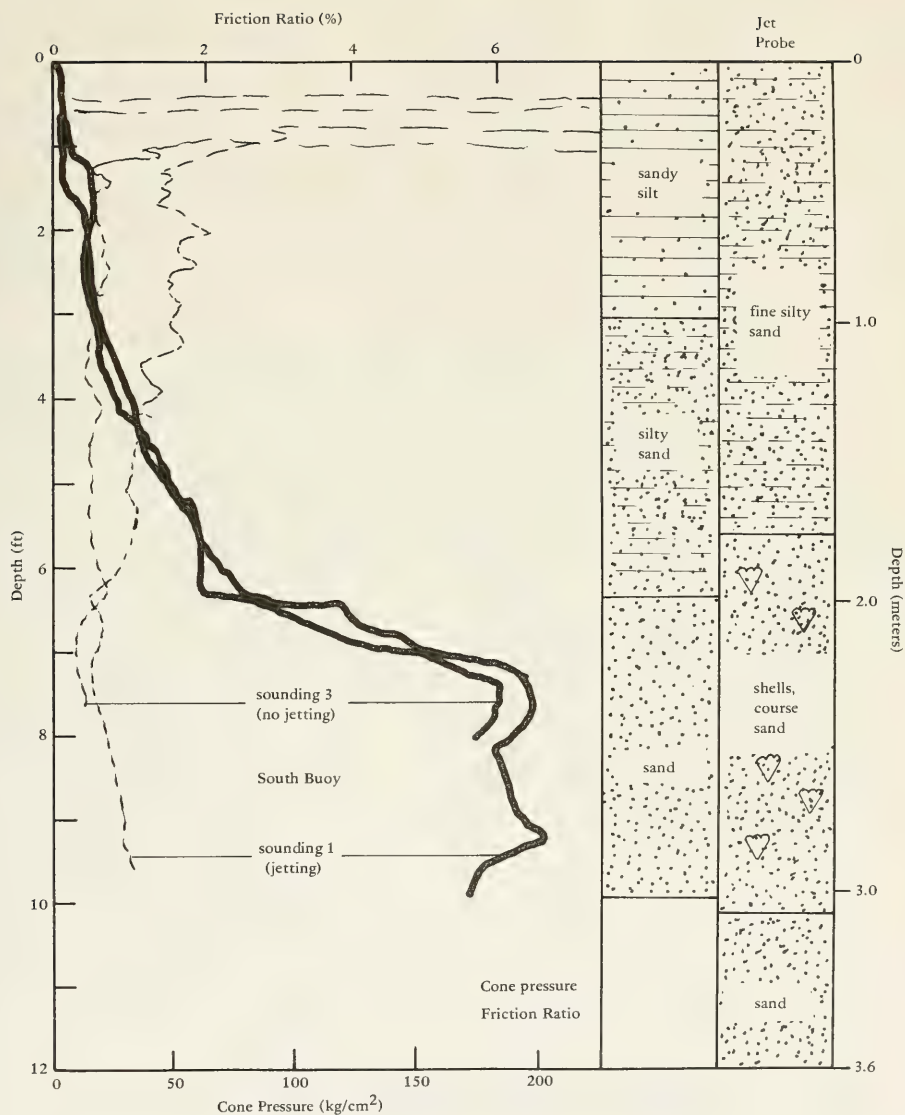


Figure 23. Cone pressure and friction ratio for Coronado XSP sounding 1 and 3 and resultant stratigraphy compared to jet probe data from same location.

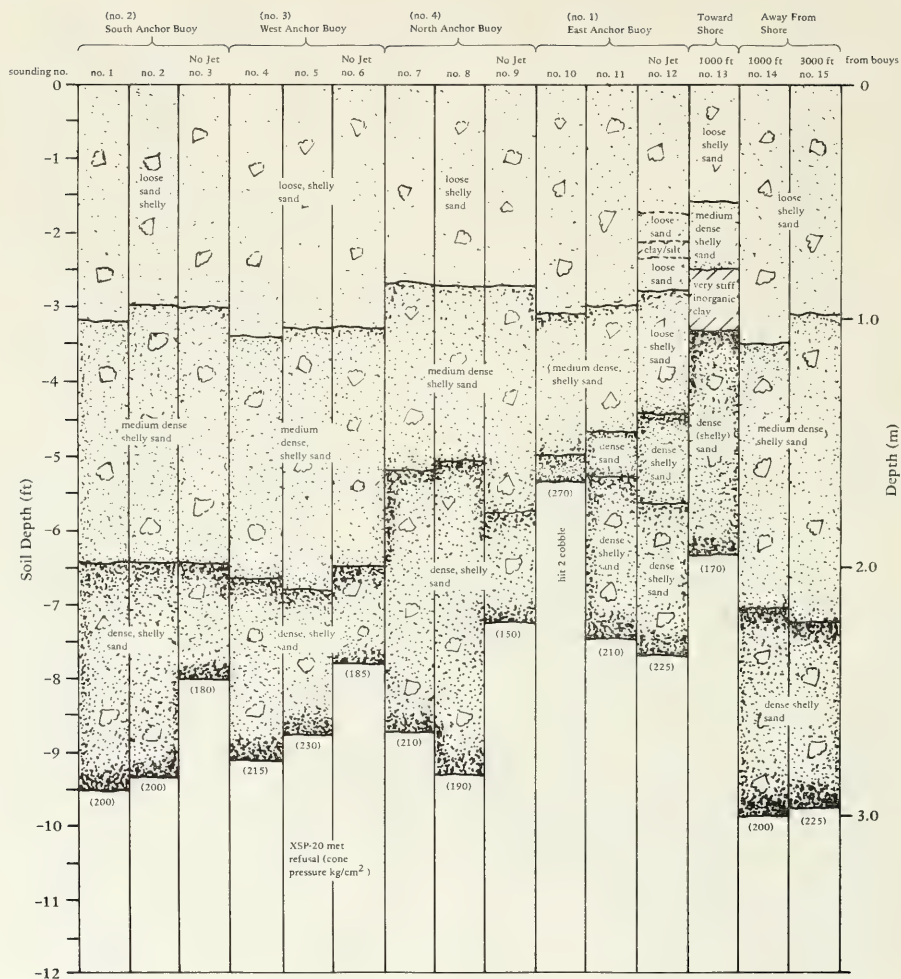


Figure 24. Stratigraphy developed from XSP data taken on 31 October 1982 at Coronado for soundings 1 through 15.



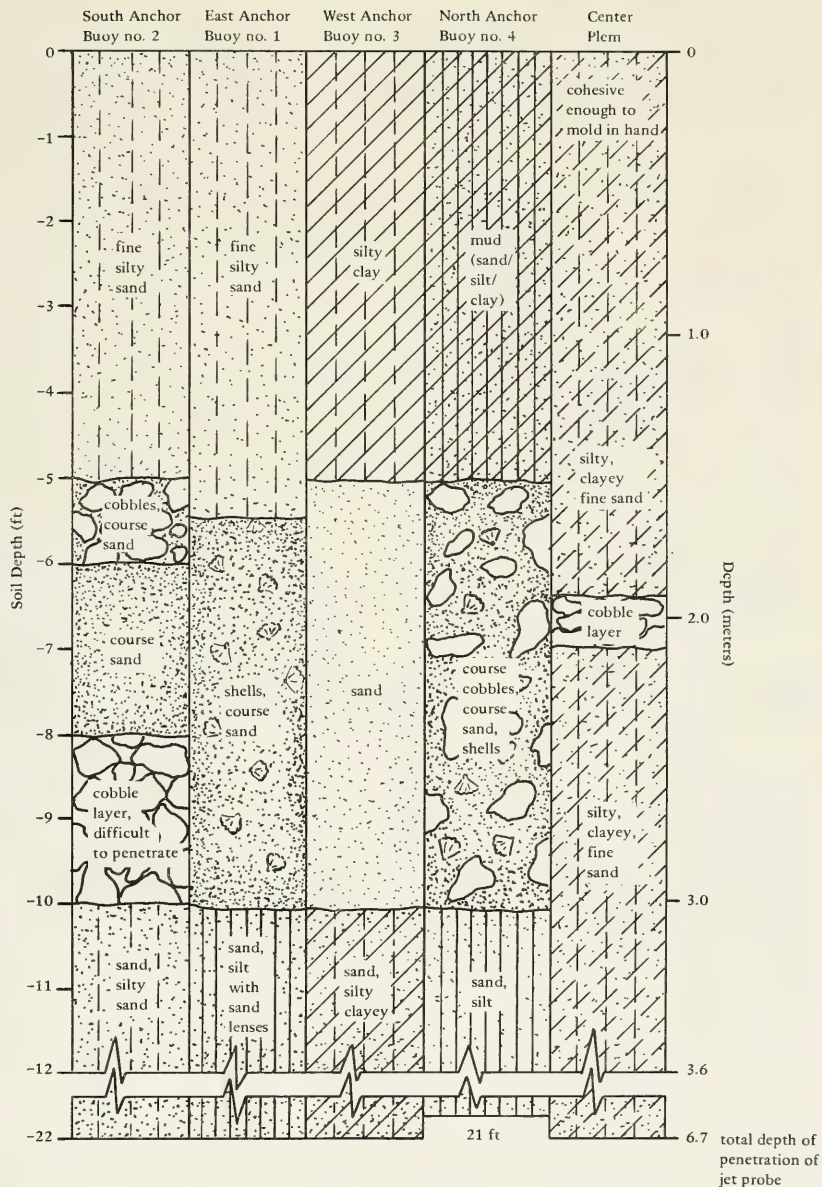


Figure 25. Jet probe data from Coronado sites (12 February 1981).

The electronics and electrical systems have performed well with the exception of the jetting sleeve. It failed several times during testing, and its use was eventually discontinued. Its purpose was to help evaluate the effect of the water jet on the data from the cone and friction sleeve as a sounding is in progress. The evaluation was done by performing side-by-side soundings with and without jetting and comparing the data.

The jetting did aid penetration. At the soundings near Port Hueneme full penetration was achieved when jetting was used (Figure 11). When it was not (Figure 10), refusal was met at a dense sand layer at 25 feet of penetration. At Coronado there was no significant difference in penetration with or without jetting (Figure 24). Refusal in all tests was essentially met at the cobble layer. However, with jetting, on the average, there was modest additional penetration. The jet was not used in Norton Sound or in San Francisco Bay.

The stratigraphies developed from the Port Hueneme (Figure 18) and the Coronado soundings (Figures 18 and 24, respectively) show that jetting does not influence the cone or friction sleeve data. In a highly layered seafloor at the Port Hueneme site, the stratigraphies developed with and without the jetting are in good agreement. For the Coronado sites, jetting and nonjetting stratigraphies are nearly identical.

Stratigraphies developed from the XSP data have been compared to historical core records and cores taken at the test sites. There are too many profiles from Norton Sound to present in this report, but in general the XSP stratigraphy compared well to the core stratigraphy. The data at Port Hueneme show good agreement to core records (Figure 19). No core was taken at the San Francisco Bay site, but the geology of the test area has been well-defined (Corps of Engineers, 1963). The test area was in young bay mud; the XSP identified the soil as a silty-clay to clayey silt. For this site, the data indicate an undrained shear strength of nearly zero at the soil surface, increasing to about 3 psi at a soil depth of 38 feet. Undrained shear strengths of these values are very indicative of young bay mud. At Coronado, no cores were taken, but the soil profile was determined with jet probings at the XSP sounding locations. The general agreement between the jet probe stratigraphy and the XSP stratigraphy is good (Figure 25).

The data acquired from replicate soundings showed good agreement, which is a recognized advantage of cone penetration testing.

## CONCLUSIONS

1. The XSP cone penetrometer is a reliable piece of equipment for gathering in-situ soil data at subbottom depth of 40 feet in up to 200 feet of water.
2. The water-jet system aids penetration but does not allow penetration through very dense sands or cobble layers.
3. The water jet, when used as described in this report, does not affect the penetrometer data.

4. The sounding data (friction sleeve and cone pressure) are repeatable from test to test.

5. The sounding data can be interpreted readily to determine soil stratigraphy (using Figure 12). This stratigraphy compares well to core records and other data used for comparison.

6. The XSP is a reliable device for gathering marine soil data to assist the Navy in siting and designing facilities and structures in marine cohesionless sediments.

## RECOMMENDATIONS

1. The XSP should be maintained ready for use on projects requiring geotechnical data. The device should be available to the Navy to assist in surveying underwater sites and in designing of seafloor facilities and structures.

2. Evaluation of the XSP cone penetrometer should be continued as it is used in various seafloors on these projects. Cores should also be taken at sounding locations to continue evaluation and perhaps for modifications of Figure 12.

3. The XSP should be updated to include a piezocone. This piezocone measures pore water pressure response, which has been shown to affect CPT data (ESOPT, 1982).

4. To increase the XSP's usefulness, the water-depth capability and soil penetration depth capability should be extended.

## ACKNOWLEDGMENTS

The contributions of Woodward-Clyde Consultants, Plymouth Meeting, Penn., and Fugro-Gulf, Inc., Houston, Tex., are appreciated. The at-sea testing in Norton Sound was supported by the U.S. Geological Survey and the Bureau of Land Management through an interagency agreement with the National Oceanic and Atmospheric Administration. The 481st Transportation Company (Heavy Boat) U.S. Army Reserve provided ship support for the tests in San Francisco Bay. The contributions of Dr. Philip Valent (now of NORDA) in the early development is acknowledged. The capable assistance of Mr. P. Babineau and the Technical Services Division of NCEL in performing at-sea tests is appreciated.

## REFERENCES

Begemann, H.K.S. (1965). "The friction jacket cone as an aid in determining the soil profile," in Proceedings, Sixth International Conference of Soil Mechanics and Foundations Engineering, vol 1, University of Toronto Press, Montreal, 8-15 Sept 1965, pp 17-20.

Beringen, F.L., Kolk, H.J., and Windle, D. (1981). "Cone penetration and laboratory testing of calcareous sediments," Symposium on Performance of Calcareous Soils, American Society for Testing Materials, Fort Lauderdale, Fla., 20 Jan 1981.

Clukey, E.C., Cacchione, D.A., and Nelson, C.H. (1978). "Liquefaction potential of Yukon prodelta," in Proceedings, May Offshore Technology Conference, Houston, Tex., Paper No. 3733, 1980.

Corps of Engineers (1963). San Francisco Bay barriers; Appendix "E", Barrier Plans: Geology, soils, and construction materials, U.S. Army Engineers District, San Francisco Corps of Engineers, Technical Report. San Francisco, Calif., Mar 1969.

deRuiter, J. (1982). "The static cone penetration test - state-of-the-art report," in Proceedings, Second European Symposium of Penetration Testing, Amsterdam, The Netherlands, May 1982. Rotterdam, The Netherlands, 1982, vol 2, pp 389-405.

Douglas, B.J. and Olsen, R.S. (1981). "Soil classification using the electric cone penetrometer; cone penetration testing and experience," in Proceedings, Geotechnical Engineering Division, American Society of Civil Engineers, St. Louis, Mo., Oct 1981.

Durgunoglu, H. and Mitchell, J.K. (1975). "Static penetration resistance of soils: I - Analysis, II - Evaluation of theory and implications for practice," Specialty Conference on In-Situ Measurement of Soil Properties, vol 1, American Society of Civil Engineers, Raleigh, N.C., 1975, pp 151-189.

ESOPT (1975). Proceedings of the European Symposium on Penetration Testing, Stockholm, Sweden, 5-7 Jan 1974, National Swedish Building Research. Stockholm, Sweden, 1975.

ESOPT (1982). Proceedings of the European Symposium on Penetration Testing, Amsterdam, The Netherlands, 24-27 May 1982. Rotterdam, The Netherlands, 1982.

Fugro-Gulf, Inc. (1981). XSP documentation, Civil Engineering Laboratory. Houston, Tex., Fugro-Gulf, Inc., Jul 1981.

Lee, H.J. (1979). Geotechnical properties of marine cohesionless sediments: evaluation of several candidate exploration techniques, Civil Engineering Laboratory, Technical Memorandum M-42-79-8. Port Hueneme, Calif., Oct 1979.

Martin, F.R. and Douglas, B.J.: Evaluation of the cone penetrometer for liquefaction hazard assessment. U.S. Geological Survey Open-file Report [1981] 81-284.



Mitchell, J.K., Guzikowski, F. and Villet, W.C.B (1978). Measurement of soil properties in-situ, present methods - their applicability and potential, Lawrence Berkeley Laboratory, University of California, Report LBL 6363. Berkeley, Calif., Mar 1978.

Norris, G.M., and Holtz, R.D. (1981). "Cone penetration testing and experience," in Proceedings, National Convention, Geotechnical Engineering Division, American Society of Civil Engineers, St. Louis, Ms., Oct 1981.

Nottingham, L.C. (1975). Use of quasi-static cone penetrometer data to predict load capacity of displacement piles, Ph.D. dissertation, Department of Civil Engineering, University of Florida. Gainesville, Fla., 1975.

Senneset, K., Janber, N., and Svan, G. (1982). "Strength and deformation parameters from cone penetration tests," in Proceedings, Second European Symposium on Penetration Testing, Amsterdam, The Netherlands, May 1982. Rotterdam, The Netherlands, 1982.

Schmertmann, J.H. (1978). Guidelines for core penetration test performance and design, U.S. Department of Transportation, Federal Highway Administration, Offices of Research and Development, Report No. FHWA-TS-78-209. Washington, D.C., 1978.

Villet, W.C.B., and Mitchell, J.K. (1981). "Cone resistance, relative density and friction angle; cone penetration testing and experience," in Proceedings, National Convention, Geotechnical Engineering Division, American Society of Civil Engineers, St. Louis, Mo., Oct 1981.

Woodward-Clyde Consultants (1980). Conceptual design of the test probe for offshore cohesionless soils, Civil Engineering Laboratory, P.O. No. N62583/79 M R575. Plymouth Meeting, Pa., Woodward-Clyde Consultants, Mar 1980.

## Appendix

### INTERPRETATION AND USE OF CPT DATA

#### CORE PENETRATION TEST (CPT) PRACTICE

The CPT was introduced in Europe about 50 years ago and recently has gained acceptance in many countries. Its initial application was to pile design as the test resembles a model pile test. However, research has extended its utility to soil classification and determination of relative density, friction angle, settlement on sand, and clay impressibility. Also, methods for designing shallow foundations from CPT data have been developed. Many papers on CPT test equipment and data interpretation can be found in the proceedings of two European Symposiums on Penetration Testing reported in ESOPT (1975) and (1982).

#### Soil Properties

Soil Classification. Efforts to classify soils with the CPT were first reported in Begemann (1965). His method was based on the ratio of sleeve friction to cone pressure (i.e., the friction ratio). In essence, he found that the friction ratio increased as median grain diameter decreased. Begemann's observations have been generally confirmed by others who developed soil classification charts. Common to classification charts is a dependence on the cone type used and the difficulty in classifying mixed (sand/silt/clay) soils. Of interest to the Navy are classification charts developed for electrical friction cones as this is the type of cone used in offshore investigations. Martin and Douglas (1981) published such a chart (Figure 12) which is perhaps the most comprehensive classification chart available. Work has also been done to extend CPT soil classification to carbonate soils (Beringen et al., 1981). In Beringen's chart, cone resistance is used to estimate the degree of cementation. Other parameters (e.g., gradation and microscopic examination) are used to further classify calcareous soils.

Relative Density. Relative density can be estimated from CPT cone pressure data but is confounded by lateral stresses, grain size, depth of overburden, and other parameters. Consequently, theoretical approaches to determining density have not proved as successful as empirical procedures. Caution, however, is warranted. Villet and Mitchell (1981) pointed out that these empirical relationships are not unique but vary according to the sand being penetrated. Schmertmann (1978) presented a plot of cone pressure versus vertical effective stress for different relative densities (Figure 26). These curves are

for normally consolidated sands. For overconsolidated sands, he suggests a method of calculating an equivalent normal consolidated sand cone pressure from the measured overconsolidated sand cone pressure for use in Figure 26.

$$\frac{q_{cOC}}{q_{cNC}} \cong 1 + \frac{3}{4} \frac{K'_{oOC}}{K'_{oNC}} - 1 \quad (1)$$

where:  $q_{cOC}$  = cone pressure for overconsolidated sand

$q_{cNC}$  = cone pressure for normally consolidated sand

$K'_{oOC}$  = coefficient of lateral pressure for overconsolidated sand

$K'_{oNC}$  = coefficient of lateral pressure for normally consolidated sand

$$\text{and } \frac{K'_{oOC}}{K'_{oNC}} \cong (OCR)^{0.42} \quad (2)$$

Villet and Mitchell have shown that this relationship can be improved by performing one or two triaxial tests to define the relative density-friction angle relationship. With this data a procedure by Durgunoglu and Mitchell (1975) can be used to develop a complete relative density, overburden pressure, cone pressure relationship. This procedure provides better accuracy but is more complex and, therefore, is not presented here. With this procedure, relative density relationships can be tailored for a particular sand.

**Friction Angle.** Friction angle for a given sand is proportional to relative density and can, therefore, be estimated from a relative density determined as described previously. An example of this type of relationship is shown in Figure 27 (Schmertmann, 1978). The relationship can be developed from one triaxial test by establishing a single point on the graph and drawing a line that follows the trend shown. Another method is shown in Figure 28 (Mitchell et al., 1978). With this graph, the friction angle can be estimated directly from the cone pressure and the overburden pressure. As with the relative density relationship of Figure 26, the curves given in Figures 27 and 28 must be applied with engineering judgment. In addition to these simple approaches for estimating friction angle, the Norwegian Institute of Technology (Senneset et al., 1982) has developed a method in which pore pressure is measured. The cone used must be a piezocone. The pore pressure information is used to convert total stress data to effective stress data, thereby eliminating some of the empiricism of previous methods.

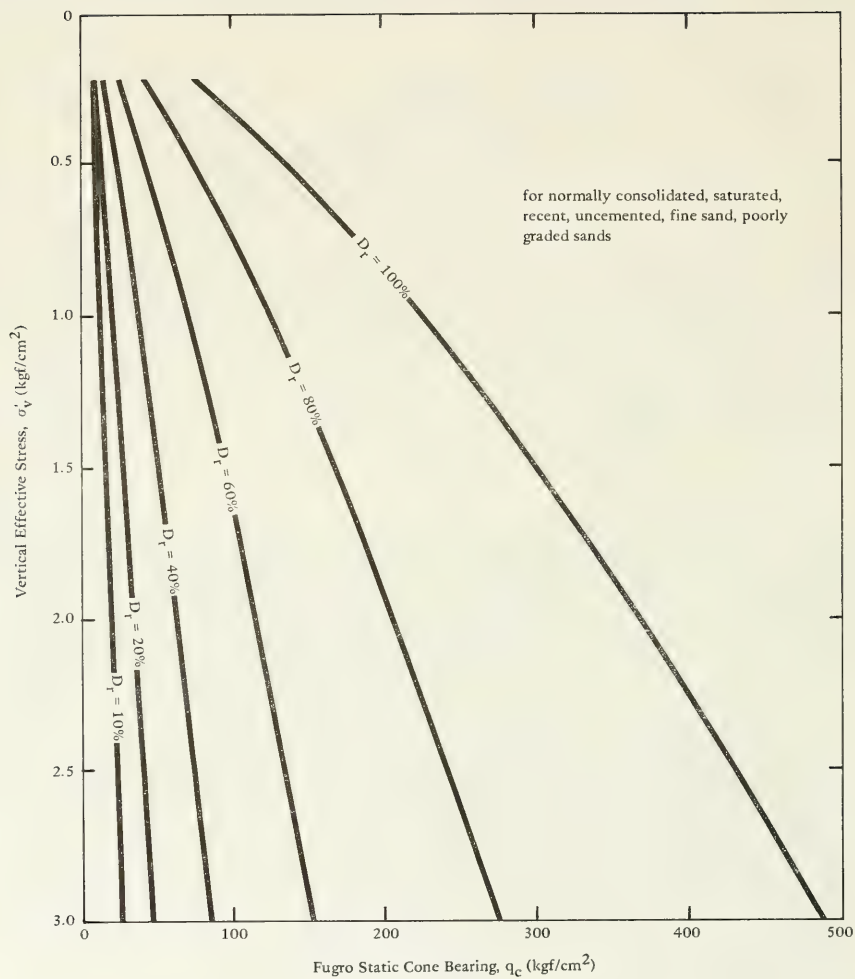


Figure 26.  $q_c$   $D_r$  correlation.



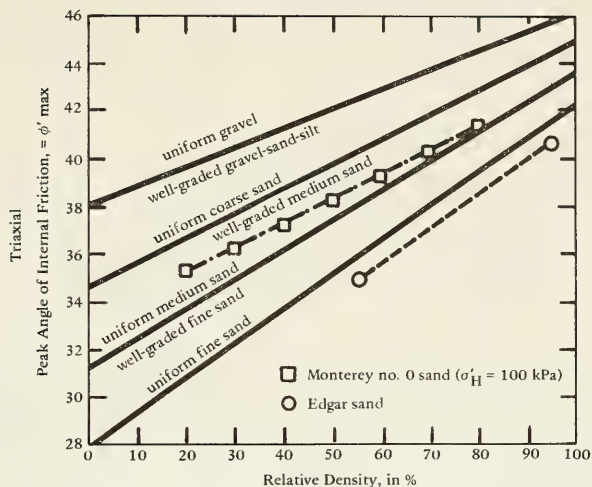


Figure 27. Triaxial cell friction angles for various sands as a function of relative density (Schmertmann, 1978).

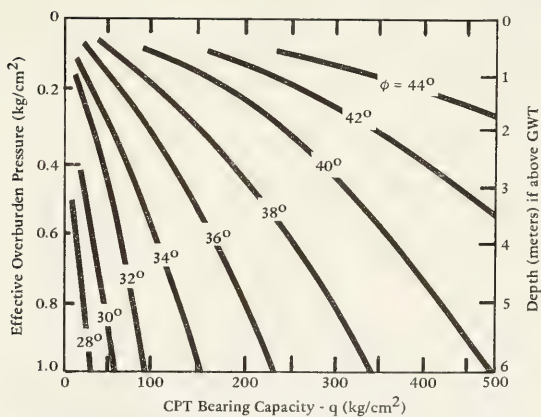


Figure 28. Method for estimating effective angle of friction ( $\phi'$ ) from static cone bearing resistance ( $q_c$ ) (from Mitchell et al., 1978).

Undrained Shear Strength of Clay. The undrained shear strength of clayey soils can be determined from the formula

$$s_u = \frac{q_c - \sigma_{vo}}{N_k} \quad (3)$$

where:  $s_u$  = undrained shear strength

$q_c$  = cone pressure

$\sigma_{vo}$  = total overburden pressure

$N_k$  = cone factor

The average value of  $N_k$  is 15 with a variation of about  $\pm 5$ . The recommendations on how to select the best  $N_k$  for reducing data are confusing. In his paper, deRuiter (1982) recommends a value of 10 to 15 for normally consolidated clays and 15 to 20 for overconsolidated clays. However, Schmertmann (1978) indicates the  $N_k$  varies according to cone type and clay strength. He says data suggest that weaker clays have higher  $N_k$ 's and stronger clays have lower  $N_k$ 's. However, each author suggests that caution be used and that a local correlation be made, preferably using a value backfigured from a failure. Further research with piezocone data may narrow the range of  $N_k$ . The work of Senneset et al. (1982) indicates that estimates of  $s_u$  can be made from cone data that include the effect of pore water pressures. By subtracting the pore water pressure piezocone data from the cone pressure some of the scatter can be reduced.

$$s_u = \frac{q_c - \mu_c}{N'_k} \quad (4)$$

where:  $\mu_c$  = pore pressure near the cone

$N'_k$  = effective cone factor ( $9 \pm 3$ )

The likely variation of  $N'_k$  is  $\pm 3$ .

### Other Properties

Estimates of the remolded strength and sensitivity of clays can be made when a friction cone is used. Schmertmann (1978) has presented these methods and states that they represent one measure of these properties. Schmertmann also indicates overconsolidation of clays can be estimated, but large errors may be involved. Compression moduli for sands and clays can be estimated with empirical correlations (Senneset et al., 1982). When a piezocone is used, the coefficient of consolidation of a clay can be roughly determined (Senneset et al., 1982).

However, the CPT test must be performed so that pore pressure dissipation curves can be determined, which means the cone must be stopped periodically. As a result, the time required to perform a cone sounding is very significantly increased.

## PILE DESIGN

Pile design from CPT data is separated into two parts: end bearing and side friction. Procedures for estimating end bearing resistance were first developed in The Netherlands several decades ago and have been under continuous development since then. Procedures for estimating frictional resistance followed the development of the friction sleeve on the CPT. The procedures that follow are for driven, straight-sided displacement piles as summarized by Schmertmann (1978).

### End Bearing Resistance

For all soils, the pile tip is assumed to be supported by a zone soil from  $0.7d$  to  $4d$  ( $d$  = pile diameter) below the tip to  $8d$  above the tip. The lowest below-tip end bearing contribution is found using the procedures shown in Figure 29. However, the cone record is searched to  $10d$  below the pile tip to check for a weaker layer of significance. If such a weaker layer is found, this governs the weakest path rule in Figure 29. For the above tip contribution, if there are a few abrupt cone pressure reductions and recoveries, they can be ignored. Because of uncertainties involved in developing cone tip pressures, a cutoff of  $300 \text{ kg/cm}^2$  is usually applied to the cone pressure. Also, pile tip pressures are limited to  $150 \text{ kg/cm}^2$  in sands and  $100 \text{ kg/cm}^2$  in very silty sands. In clays, these procedures have been found applicable when undrained shear strengths are less than  $7 \text{ psi}$ . For higher strength clays, Schmertmann recommends reducing end bearing according to the adhesion factors given in Figure 30. These factors will reduce tip capacity by a larger percentage as soil strength increases.

### Side Friction

Nottingham (1975) developed an empirical procedure for estimating pile friction that can be applied to both sands and clay soils. This procedure has the advantage that a direct measure of soil adhesion is used in the design. The formula used is:

$$Q_s = K_{s,c} \left\{ \sum_{\ell=0}^{8d} \frac{\ell}{8d} f_s A'_s + \sum_{\ell=0}^L f_s A'_s \right\} \quad (5)$$

where:  $Q_s$  = total ultimate pile friction

$K_{s,c}$  = correction factors for sands and clays to be applied to  $f_s$

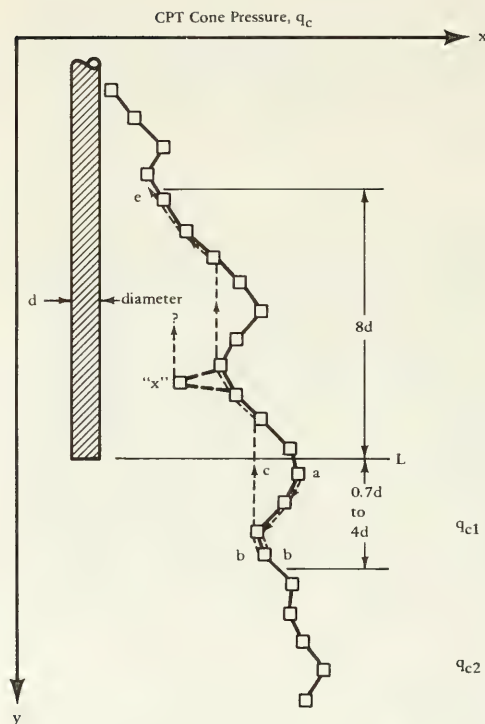
$\ell$  = depth to which  $f_s$  is being considered

$d$  = pile diameter

$f_s$  = unit local friction sleeve resistance

$A'_s$  = pile-soil contact area over  $f_s$  depth interval

$L$  = total embedded pile length



$$\text{pile end bearing} = q_p = \frac{q_{c1} + q_{c2}}{2}$$

$q_{c1}$  = Average  $q_c$  over a distance of  $y$  (diameter), when  $y$  is any value ( $y \geq d$ ) below the pile tip (path a-b-c). Sum  $q_c$  values in both the downward (path a-b) and upward (path b-c) directions. Use actual  $q_c$  values along path a-b and the minimum path rule along path b-c. Compute  $q_{c1}$  for  $y$ -values from  $0.7d$  to  $4.0d$  and use the minimum  $q_{c1}$  value obtained.

$q_{c2}$  = Average  $q_c$  over a distance of  $8d$  above the pile tip (path c-e). Use the minimum path rule as for path b-c in the  $q_{c1}$  computations. Ignore any minor "x" peak depressions if in sand, but include in minimum path if in clay.

Figure 29. Dutch procedure for predicting pile tip capacity (from Schmertmann, 1978).

The correction factors  $K_s$  and  $K_c$  can be found in Figure 31. Other procedures are also available and are reported by Schmertmann (1978). One method involves estimating  $s_u$  and then reducing it by multiplying by the factor given in Figure 30. Another incorporates effective stress by including overburden pressure but still relies on an empirically derived factor. The method presented herein has been demonstrated by Schmertmann and has given good results; therefore it is recommended. Negative side friction caused by downloading on the pile by the soil is usually taken as two-thirds of the positive friction values.



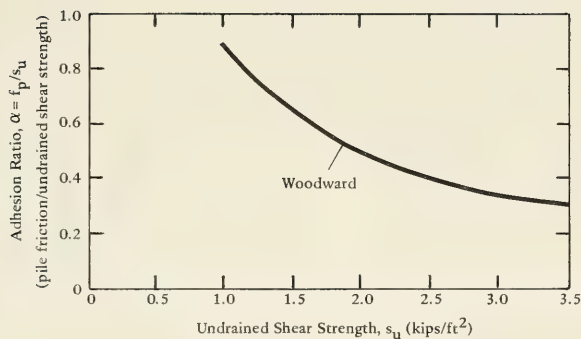


Figure 30. Correlations of clay adhesion-pile ratio with undrained shear strength (Schmertmann, 1978).

The factor of safety recommended by Schmertmann for piles designed from electrical friction cones is 2.25. This factor is applicable to tip bearing and side friction and should result in a factor of safety of at least 2.0 to the yield point.

Methods are also available for analyzing tapered piles, friction with no friction sleeve data, capacity variations due to pile shape, and insertion method. The reader is referred to Schmertmann (1978) for these details.

### Bearing Capacity

Bearing capacity can be estimated by the Terzaghi bearing capacity equation or by graphs that convert cone pressure directly to bearing capacity. Schmertmann recommends using the Terzaghi equation, which is valid for footing embedment to  $D/B \leq 1.5$  (depth to width or diameter ratio).

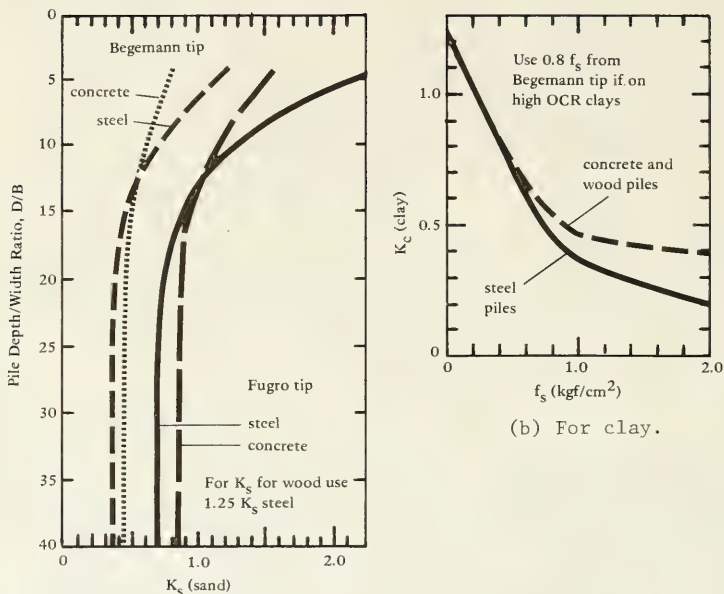
$$q = \gamma \frac{B}{2} N_y + DN_q + cN_c \quad (6)$$

where:  $q$  = unit bearing capacity  
 $\gamma$  = unit weight of soil  
 $B$  = footing width or diameter  
 $D$  = footing depth  
 $c$  = soil cohesion

$N_y, N_q, N_c$  = bearing capacity factors

$N_y$  and  $N_q$  are estimated as

$$0.8 N_y \approx 0.8 N_q \approx \bar{q}_{c0-1.5 B} \quad \text{in kgf/cm}^2 \quad (7)$$



(a) For sand.

(b) For clay.

Figure 31. Correction factors to be applied in Equation 5 (Nottingham, 1975) (from Schmertmann, 1978).

where  $\bar{q}_c$  is the average cone pressure from the soil surface to a depth of 1.5 footing widths (kgf/cm<sup>2</sup>).

A factor of safety of 2 to 3 is then applied to obtain the allowable bearing pressure. This procedure will result in error if the cone pressure is being significantly affected by pore pressure effects.

Clay bearing capacity is more directly related to the cone pressure. For shallow footing, the cone pressure for 1.5 footing widths below the footing can be averaged to obtain the ultimate footing pressure. The allowable bearing pressure is obtained by applying a factor of safety of 2 to 3.

### Settlement

Settlement of footings on sand and clays can be estimated using CPT data. The results for sand are quite adequate for the static loading conditions for which the procedures apply. For clays, more uncertainty exists, and the results give more of a qualitative indication of settlement rather than a quantitative estimation. The procedures involved in making settlement estimates are too involved to present here. The reader is referred to Schmertmann (1978) for details regarding these procedures.

## LIST OF SYMBOLS

$A'_s$	pile-soil contact area over $f_s$ depth interval
$B$	footing width or diameter
$c$	soil cohesion
$D$	footing depth
$D_r$	relative density
$d$	pile diameter
$f_s$	unit local friction sleeve resistance
GWT	ground water table
$K_{s,c}$	correction factors for sands and clays to be applied to $f_s$
$K'_{oOC}$	coefficient of lateral pressure for overconsolidated sand
$K'_{oNC}$	coefficient of lateral pressure for normally consolidated sand
$L$	total embedded pile length
$l$	depth $f_s$ being considered
$N'_k$	effective cone factor (9 or $\pm 3$ )
$N, N_q, N_c$	bearing capacity factors
$N_k$	cone factor
OCR	overconsolidation ratio
$Q_s$	total ultimate pile friction
$\bar{q}_c$	average cone pressure from the soil surface to a depth of 1.5 footing widths (kgf/cm <sup>2</sup> )
$q$	unit bearing capacity
$q_c$	cone pressure
$q_{cOC}$	cone pressure for overconsolidated sand
$q_{cNC}$	cone pressure for normally consolidated sand
$s_u$	undrained shear strength

$\sigma_{vo}$	total overburden pressure (vertical)
$\mu_c$	pore pressure near cone
$\gamma$	unit weight of soil
$\alpha$	adhesion ratio
$\phi$	angle of internal friction



## DISTRIBUTION LIST

AFB Hq Space Com/Deeq (P. Montoya) Peterson AFB, CO  
 AF HQ Traffic Mgmt Cargo Br (LTC S. Rohrbough) Washington,DC  
 AFB AF Tech Office (Mgt & Ops), Tyndall, FL; AUL/LSE 63-465, Maxwell AL; Elec Sys Div. Code OCRS  
 (LTC M. Traister) Hanscom, MA; Scol of Engrng (AFIT/DET)  
 NATL ACADEMY OF ENG. Alexandria, VA  
 ARCTICSUBLAB Code 54, San Diego, CA  
 ARMY BMDSC-RE (H. McClellan) Huntsville AL; DAEN-MPE-D Washington DC; HODA (DAEN-FEE-A);  
 R&D Command DRDNA-UST) (J. Siegel) Natick, MA  
 ARMY - CERL Spec Assist for MILCON, Champaign, IL  
 ARMY COE Philadelphia Dist. (LIBRARY) Philadelphia, PA  
 ARMY CORPS OF ENGINEERS MRD-Eng. Div., Omaha NE; Seattle Dist. Library, Seattle WA  
 ARMY CRREL A. Kovacs, Hanover NH; Library, Hanover NH  
 ARMY DARCOM Code DRCMM-CS Alexandria VA  
 ARMY ENG WATERWAYS EXP STA Coastal Eng Rsrch Cntr, Vicksburg, MS; Library, Vicksburg MS  
 ARMY ENGR DIST. Library, Portland OR  
 ARMY ENVIRON. HYGIENE AGCY HSE-EW Water Qual Eng Div Aberdeen Prov Grnd MD  
 ARMY LOGISTICS COMMAND Code ALC/ATCL-MS (Morrissett) Fort Lee, VA  
 ARMY MAT SYS ANALYSIS ACT Code DRXSY-CM (M Ogorzalek) Aberdeen Proving Grnd MD  
 ARMY MATERIALS & MECHANICS RESEARCH CENTER Dr. Lenoe, Watertown MA  
 ARMY MOBIL EQUIP R&D COM DRDME-GS Fuel Tech Br, Ft Belvoir, VA  
 ARMY MTMC Trans Engr Agency MTT-CE, Newport News, VA  
 ARMY TRANSPORTATION SCHOOL Code ATSP0 CD-TE Fort Eustis, VA  
 ARMY TRNG & DOCTRINE CMD Code ATCD-SL Fort Monroe, VA  
 ARMY-MERADCOM CFLO Engr Fort Belvoir VA; DRDME-MR (J. Sargent) Ft. Belvoir VA; DRDME-WC  
 Ft Belvoir VA  
 ASST SECRETARY OF THE NAVY Spec. Assist Submarines, Washington DC  
 BUREAU OF RECLAMATION Code 1512 (C. Selander) Denver CO  
 CINCLANT CIV ENGR SUPP PLANS OFFR NORFOLK, VA  
 CINCPAC Fac Engrng Div (J44) Makalapa, HI  
 CNM Code 03462, Washington DC; Code 043 Washington DC; Code MAT-04, Washington, DC; MAT-0718,  
 Washington, DC; NMAT - 044, Washington DC  
 CNO Code NOP-964, Washington DC; Code OP 323, Washington DC; Code OP 424, Washington DC; Code OP  
 414, Washington DC; Code OP 97 Washington DC; Code OP 97 Washington, DC; Code OP 987 Washin  
 DC; Code OP323 Washington DC; Code OPNAV 09B24 (H); Code OPNAV 22, Wash DC; Code OPNAV  
 23, Wash DC; OP-411F, Wash DC; OP987J, Washington, DC  
 COMCBLANT Code S3T  
 COMCBPAC Operations Off, Makalapa HI  
 COMDEVGRUONE CMDR San Diego, CA  
 COMFAIRMED SCE, Code N55, Naples IT  
 COMFLEACT, OKINAWA SCE, Yokosuka Japan  
 COMNAVBEACHPHIBREFTRAGRU ONE San Diego CA  
 COMNAVMARIANAS Code N4, Guam  
 COMNAVSUPFORANTARCTICA PWO Det Christchurch  
 COMNAVSURFLANT Code N-4, Norfolk, VA  
 COMRNCF Nicholson, Tampa, FL  
 COMSUBDEVGRUONE Operations Offr, San Diego, CA  
 COMUSNAVCENT N42, Pearl Harbor, HI  
 NAVSURFPAC Code N-4, Coronado  
 COMOPTEVFOR CMDR, Norfolk, VA; Code 705, San Diego, CA  
 DEFENSE INTELLIGENCE AGENCY DB-4C1 Washington DC  
 DEFFUELSUPPCEN DFSC-OWE (Term Engrng) Alexandria, VA; DFSC-OWE, Alexandria VA  
 DLSIE Army Logistics Mgt Center, Fort Lee, VA  
 DNA STTL, Washington DC  
 DOE Div Ocean Energy Sys Cons/Solar Energy Wash DC  
 DTIC Defense Technical Info Ctr/Alexandria, VA  
 DTNSRDC Anna Lab (Code 1175) Annapolis MD; Anna Lab (Code 119) Annapolis MD; Anna Lab (Code  
 1568) Annapolis MD; Anna Lab (Code 4120) Annapolis MD; Anna Lab, Code 2724 (D Bloomquist)  
 Annapolis, MD  
 FMFLANT CEC Offr, Norfolk VA  
 FMFPAC CG(FEO) Camp Smith, HI  
 FOREST SERVICE Engr Staff Washington, DC  
 GIDEP OIC, Corona, CA

GSA Assist Comm Des & Cnst (FAIA) D R Dibner Washington, DC  
 HCU ONE CO, Bishops Point, HI  
 LIBRARY OF CONGRESS Washington, DC (Sciences & Tech Div)  
 MARCORPS Code LME-1 (Riggs) Washington, DC  
 MCB 1st For Serv Supp Gru (Engr Sup Ofcr) Camp Pendleton CA  
 MARINE CORPS BASE PWO, Camp Pendleton CA; PWO, Camp S. D. Butler, Kawasaki Japan  
 MCAS Facil. Engr. Div, Cherry Point NC; CO, Kaneohe Bay HI; Facs Maint Dept - Operations Div, Cherry Point  
 MCDEC M&L Div (LTC R. Kerr) Quantico, VA; M&L Div Quantico VA; NSAP REP, Quantico VA  
 MCRD SCE, San Diego CA  
 MILITARY SEALIFT COMMAND Washington DC  
 NAF PWO, Atsugi Japan  
 NALF OINC, San Diego, CA  
 NARF Code 100, Cherry Point, NC; Equipment Engineering Division (Code 61000), Pensacola, FL  
 NAS PWD - Engr Div, Oak Harbor, WA; PWD Maint. Div., New Orleans, Belle Chasse LA; PWD, Code 1821H (Pfankuch) Miramar, SD CA; PWO (Code 18.2), Bermuda; PWO Belle Chasse, LA; PWO Key West FL; PWO Patuxent River MD; PWO, Cecil Field FL; PWO, Glenview IL; PWO, So. Weymouth MA; SCE Norfolk, VA  
 NATL BUREAU OF STANDARDS Kovacs, Washington, D.C.; R Chung Washington, DC  
 NATL RESEARCH COUNCIL Naval Studies Board, Washington DC  
 NAVACT PWO, London UK  
 NAVAEROSPREGMEDCEN SCE, Pensacola FL  
 NAVAIRDEVCEEN Code 813, Warminster PA  
 NAVAIRSYSCOM Code 41712A (Michols) Washington, DC  
 NAVCHAPGRU CO Williamsburg VA; Operations Officer, Code 30 Williamsburg, VA  
 NAVCOASTSYSCEN CO, Panama City FL; Code 715 (J Quirk) Panama City, FL; Code 715 (J. Mittleman) Panama City, FL; Code 719, Panama City, FL; Code 772 (C B Koesy) Panama City FL; Library Panama City, FL; PWO Panama City, FL  
 NAVCOMMAREAMSTRSTA SCE Unit 1 Naples Italy; SCE, Wahiawa HI; Sec Offr, Wahiawa, HI  
 NAVCOMMSTA Code 401 Nea Makri, Greece; PWD - Maint Control Div, Diego Garcia Is.; PWO, Exmouth, Australia  
 NAVCONSTRACEN Curriculum/Instr. Stds Offr, Gulfport MS  
 NAVEDTRAPRODEVCEEN Technical Library, Pensacola, FL  
 NAVLEXSYSCOM Code PME 124-61, Washington, DC; PME 124-612, Wash DC  
 NAVEODTECHCEN Code 605, Indian Head MD  
 NAVFAC PWO, Centerville Bch, Ferndale CA  
 NAVFACENGCOM Alexandria, VA; Code 03 Alexandria, VA; Code 03T (Essoglou) Alexandria, VA; Code 04T4 (D. Potter) Alexandria, VA; Code 04T5, Alexandria, VA; Code 04A1 Alexandria, VA; Code 06, Alexandria VA; Code 09M54, Tech Lib, Alexandria, VA; Code 100, Alexandria, VA; Code 1002B (J. Leimanis) Alexandria, VA; Code 1113, Alexandria, VA  
 NAVFACENGCOM - CHES DIV. Code 405 Wash. DC; Code 407 (D Scheesele) Washington, DC; Code FPO-1C Washington DC; Code FPO-1E, Wash. DC; FPO-1 Washington, DC; Code 11, Washington DC; FPO-1P/1P3 Washington, DC; Library, Washington, D.C.  
 NAVFACENGCOM - LANT DIV. Code 1112, Norfolk, VA; Code 405 Civil Engr BR Norfolk VA; Eur. BR Deputy Dir, Naples Italy; Library, Norfolk, VA  
 NAVFACENGCOM - NORTH DIV. (Boretsky) Philadelphia, PA; CO; Code 04 Philadelphia, PA; Code 04AL, Philadelphia PA; Code 09P Philadelphia PA; ROICC, Contracts, Crane IN  
 NAVFACENGCOM - PAC DIV. CODE 09P PEARL HARBOR HI; Code 2011 Pearl Harbor, HI; Code 402, RDT&E, Pearl Harbor HI; Library, Pearl Harbor, HI  
 NAVFACENGCOM - SOUTH DIV. Code 1112, Charleston, SC; Code 406 Charleston, SC; Library, Charleston, SC  
 NAVFACENGCOM - WEST DIV. Code 04B San Bruno, CA; Library, San Bruno, CA; 09P/20 San Bruno, CA; RDT&ELO San Bruno, CA  
 NAVFACENGCOM CONTRACTS Dir. of Constr, Tupman, CA; Eng Div dir, Southwest Pac, Manila, PI; OICC, Southwest Pac, Manila, PI; OICC/ROICC, Balboa Panama Canal; OICC/ROICC, Norfolk, VA; ROICC Code 495 Portsmouth VA; ROICC Key West FL; ROICC, Keflavik, Iceland; ROICC, NAS, Corpus Christi, TX; ROICC, Yap  
 NAVFORCARIB Commander (N42), Puerto Rico  
 NAVMAG Security Offr, Hawaii  
 NAVOCEANO Library Bay St. Louis, MS  
 NAVOCEANSYSCEN Code 09 (Talkington), San Diego, CA; Code 4473 Bayside Library, San Diego, CA; Code 4473B (Tech Lib) San Diego, CA; Code 5204 (J. Stachiw), San Diego, CA; Code 5214 (H. Wheeler), San Diego CA; Code 5221 (R.Jones) San Diego Ca; Code 5322 (Bachman) San Diego, CA; Hawaii Lab (R Yumori) Kailua, HI; Hi Lab Tech Lib Kailua HI  
 NAVPGSCOL C. Morers Monterey CA; Code 61WL (O. Wilson) Monterey CA; E. Thornton, Monterey CA

NAVPHIBASE CO, ACB 2 Norfolk, VA; COMNAVBEACHGRU TWO Norfolk VA; Dir. Amphib. Warfare  
 Brd Staff, Norfolk, VA; Harbor Clearance Unit Two, Little Creek, VA; PWO Norfolk, VA; SCE  
 Coronado, SD,CA; UDT 21, Little Creek, VA  
 NAVREGMEDCEN SCE, SCE, Guam  
 NAVSCOLCECOFF C35 Port Hueneme, CA  
 NAVSCOL PWO, Athens GA  
 NAVSEASYS COM Code 0325, Program Mgr, Washington, DC; Code OOC-D, Washington, DC; Code PMS  
 395 A 3, Washington, DC; Code PMS 395 A2, Washington, DC; Code PMS 396.3311 (Rekas), Wash., DC;  
 Code SEA OOC Washington, DC; PMS-395 A1, Washington, DC; PMS395-A3, Washington, DC  
 NAVSECGRUACT PWO Winter Harbor ME; PWO, Adak AK  
 NAVSECGRUCOM Code G43, Washington DC  
 NAVSHIPREPAC Library, Guam; SCE Subic Bay  
 NAVSHIPYD Bremerton, WA (Carr Inlet Acoustic Range); Code 202.4, Long Beach CA; Code 202.5  
 (Library) Puget Sound, Bremerton WA; Code 280, Mare Is., Vallejo, CA; Code 280.28 (Goodwin), Vallejo,  
 CA; Code 380, Portsmouth, VA; Code 440 Portsmouth NH; Code 440, Puget Sound, Bremerton WA; PWO  
 Charleston Naval Shipyard, Charleston SC; Tech Library, Vallejo, CA  
 NAVSTA CO Roosevelt Roads P.R. Puerto Rico; Code 16P, Keflavik, Iceland; Dir Engr Div, PWD, Mayport  
 FL; PWD (LTJG.P.M. Motolenich), Puerto Rico; PWO, Keflavik Iceland; PWO, Mayport FL; SCE, Guam,  
 Marianas; SCE, Subic Bay, R.P.; Security Offr, San Francisco, CA  
 NAVSUPPO Security Offr, Sardinia  
 NAVSURFWPCEN PWO, Dahlgren VA  
 NAVTECHTRACEN SCE, Pensacola FL  
 NAVWARCOL Dir. of Facil., Newport RI  
 NAVWPNCEN Code 2636 China Lake  
 NAVWPNSTA Code 092, Colts Neck NJ; Engrng Div, PWD Yorktown, VA  
 NAVWPNSTA PW Office Yorktown, VA  
 NAVWPNSTA PWD - Maint. Control Div., Concord, CA; PWD - Supr Gen Engr, Seal Beach, CA; PWO Colts  
 Neck, NJ; PWO, Charleston, SC; PWO, Seal Beach CA  
 NAVWPNSUPPCEN Code 09 Crane IN  
 NCTC Const. Elec. School, Port Hueneme, CA  
 NCBC Code 10 Davisville, RI; Code 15, Port Hueneme CA; Code 155, Port Hueneme CA; Code 1552 (Brazele)  
 Port Hueneme, CA; Code 155B (Nishimura) Port Hueneme, CA; Code 156, Port Hueneme, CA; Code 156F  
 (Volpe) Port Hueneme, CA; Code 1571, Port Hueneme, CA; Library, Davisville, RI; Technical Library,  
 Gulfport, MS  
 NCBU 411 OIC, Norfolk VA  
 NCR 20, Commander; 30, Guam, Commander; 30th Det, OIC, Diego Garcia I  
 NMCB 3, SWC D, Wellington; 74, CO; FIVE, Operations Dept; THREE, Operations Off.  
 NOAA (Mr. Joseph Vadus) Rockville, MD; Library Rockville, MD  
 NORDA Code 410 Bay St. Louis, MS; Code 440 (Ocean Rsch Off) Bay St. Louis MS; Code 500, (Ocean Prog  
 Off-Ferer) Bay St. Louis, MS  
 NRL Code 5800 Washington, DC; Code 5843 (F. Rosenthal) Washington, DC; Code 8441 (R.A. Skop),  
 Washington DC  
 NSC SCE Norfolk, VA  
 NSD SCE, Subic Bay, R.P.  
 NTC OICC, CBU-401, Great Lakes IL  
 NUCLEAR REGULATORY COMMISSION T.C. Johnson, Washington, DC  
 NUSC DET Code EA123 (R.S. Munn), New London CT; Code TA131 (G. De la Cruz), New London CT  
 OFFICE SECRETARY OF DEFENSE ASD (MRA&L) Code CSS/CC Washington, DC  
 ONR Central Regional Office, Boston, MA; Code 481, Bay St. Louis, MS; Code 485 (Silva) Arlington, VA;  
 Code 700F Arlington VA  
 PERRY OCEAN ENG R. Pellen, Riviera Beach, FL  
 PHIBCB 1 P&E, San Diego, CA; 1, CO San Diego, CA  
 PMTC Code 3144, (E. Good) Point Mugu, CA; Code 3331 (S. Opatowsky) Point Mugu, CA; EOD Mobile  
 Unit, Point Mugu, CA  
 PWC CO, (Code 10), Oakland, CA; Code 10, Great Lakes, IL; Code 105, Oakland, CA; Code 121.1, Oakland,  
 CA; Code 128, Guam; Code 154 (Library), Great Lakes, IL; Code 200, Great Lakes IL; Code 400, Great  
 Lakes, IL; Code 400, Pearl Harbor, HI; Code 400, San Diego, CA; Code 420, Great Lakes, IL; Code 420,  
 Oakland, CA; Code 424, Norfolk, VA; Code 500 Norfolk, VA; Code 500, Great Lakes, IL; Code 700, Great  
 Lakes, IL; Code 700, San Diego, CA; Code 800, San Diego, CA; Library, Code 120C, San Diego, CA;  
 Library, Guam; Library, Norfolk, VA; Library, Pearl Harbor, HI; Library, Pensacola, FL; Library, Subic  
 Bay, R.P.; Library, Yokosuka JA; Production Officer, Norfolk, VA  
 SUPANX PWO, Williamsburg VA  
 UCT ONE OIC, Norfolk, VA  
 UCT TWO OIC, Port Hueneme CA  
 U.S. MERCHANT MARINE ACADEMY Kings Point, NY (Reprint Custodian)

US DEPT OF INTERIOR Bur of Land Mgmt Code 583, Washington DC  
 US GEOLOGICAL SURVEY Off. Marine Geology, Piteleki, Reston VA  
 US NATIONAL MARINE FISHERIES SERVICE Highlands NY (Sandy Hook Lab-Library)  
 US NAVAL FORCES Korea (ENJ-P&O)  
 USCG (G-MP-3/USP/82) Washington Dc: G-EOE-4 (T Dowd), Washington, DC; Library Hqs Washington, DC  
 USCG R&D CENTER CO Groton, CT; D. Motherway, Groton CT; Library New London, CT  
 USDA Ext Service (T. Maher) Washington, DC; Forest Service Reg 3 (R. Brown) Albuquerque, NM; Forest Service, San Dimas, CA  
 USNA ENGRNG Div, PWD, Annapolis MD  
 USS AJAX Repair Officer, San Francisco, CA  
 WATER & POWER RESOURCES SERVICE (Smoak) Denver, CO  
 ADVANCED TECHNOLOGY F. Moss, Op Cen Camarillo, CA  
 BERKELEY PW Engr Div, Harrison, Berkeley, CA  
 CALIF. DEPT OF NAVIGATION & OCEAN DEV. Sacramento, CA (G. Armstrong)  
 CALIF. MARITIME ACADEMY Vallejo, CA (Library)  
 CALIFORNIA INSTITUTE OF TECHNOLOGY Pasadena CA (Keck Ref, Rm)  
 CALIFORNIA STATE UNIVERSITY (Yen) Long Beach, CA; LONG BEACH, CA (CHELAPATI)  
 COLORADO STATE UNIV., FOOTHILL CAMPUS Fort Collins (Nelson)  
 CORNELL UNIVERSITY Ithaca NY (Serials Dept, Engr Lib.); (Dr. F.Kulnawy) Dept of Civil & Environ Engrng, Ithaca, NY  
 DAMES & MOORE LIBRARY LOS ANGELES, CA  
 DUKE UNIV MEDICAL CENTER B. Muga, Durham NC; DURHAM, NC (VESIC)  
 FLORIDA ATLANTIC UNIVERSITY Boca Raton, FL (McAllister)  
 HARVARD UNIV. Dept. of Architecture, Dr. Kim, Cambridge, MA  
 GEORGIA INSTITUTE OF TECHNOLOGY Atlanta GA (B. Mazanti)  
 INSTITUTE OF MARINE SCIENCES Morehead City NC (Director)  
 IOWA STATE UNIVERSITY Ames IA (CE Dept, Handy)  
 WOODS HOLE OCEANOGRAPHIC INST. Woods Hole MA (Winget)  
 LEHIGH UNIVERSITY BETHLEHEM, PA (MARINE GEOTECHNICAL LAB., RICHARDS); Bethlehem PA (Fritz Engr. Lab No. 13, Beedle); Bethlehem PA (Linderman Lib. No.30, Flecksteiner)  
 MAINE MARITIME ACADEMY CASTINE, ME (LIBRARY)  
 MICHIGAN TECHNOLOGICAL UNIVERSITY Houghton, MI (Haas)  
 MIT Cambridge MA; Cambridge MA (Rm 10-500, Tech. Reports, Engr. Lib.); Cambridge MA (Whitman)  
 NATL ACADEMY OF ENG. ALEXANDRIA, VA (SEARLE, JR.)  
 NATURAL ENERGY LAB Library, Honolulu, HI  
 NEW MEXICO SOLAR ENERGY INST. Dr. Zwibel Las Cruces NM  
 OREGON STATE UNIVERSITY (CE Dept Grace) Corvallis, OR; CORVALLIS, OR (CE DEPT, BELL); Corvallis OR (School of Oceanography)  
 PENNSYLVANIA STATE UNIVERSITY STATE COLLEGE, PA (SNYDER); State College PA (Applied Rsch Lab); UNIVERSITY PARK, PA (GOTOLSKI)  
 PORT SAN DIEGO Pro Eng for Port Fac, San Diego, CA  
 PORTLAND STATE UNIVERSITY H. Migliore Portland, OR  
 PURDUE UNIVERSITY Lafayette IN (Leonards); Lafayette, IN (Altschaeffl); Lafayette, IN (CE Engr. Lib)  
 SAN DIEGO STATE UNIV. I. Noorany San Diego, CA  
 SCRIPPS INSTITUTE OF OCEANOGRAPHY LA JOLLA, CA (ADAMS)  
 SEATTLE U Prof Schwaegler Seattle WA  
 SOUTHWEST RSCH INST King, San Antonio, TX; R. DeHart, San Antonio TX  
 STATE UNIV. OF NEW YORK Buffalo, NY; Fort Schuyler, NY (Longobardi)  
 TEXAS A&M UNIVERSITY College Station TX (CE Dept, Herbich)  
 UNIVERSITY OF ALASKA Doc Collections Fairbanks, AK; Marine Science Inst. College, AK  
 UNIVERSITY OF CALIFORNIA A-031 (Storms) La Jolla, CA; BERKELEY, CA (CE DEPT, GERWICK); BERKELEY, CA (CE DEPT, MITCHELL); Berkeley CA (Dept of Naval Arch.); Berkeley CA (E. Pearson); DAVIS, CA (CE DEPT, TAYLOR); La Jolla CA (Acq. Dept. Lib. C-075A); M. Duncan, Berkeley CA  
 UNIVERSITY OF CONNECTICUT Groton CT (Inst. Marine Sci, Library)  
 UNIVERSITY OF DELAWARE Newark, DE (Dept of Civil Engineering, Chesson)  
 UNIVERSITY OF HAWAII HONOLULU, HI (SCIENCE AND TECH. DIV.); Ocean Engrng Dept  
 UNIVERSITY OF ILLINOIS (Hall) Urbana, IL; Metz Ref Rm, Urbana IL; URBANA, IL (DAVISSON); URBANA, IL (LIBRARY)  
 UNIVERSITY OF MASSACHUSETTS (Heronemus), ME Dept, Amherst, MA  
 UNIVERSITY OF MICHIGAN Ann Arbor MI (Richart)  
 UNIVERSITY OF NEBRASKA-LINCOLN Lincoln, NE (Ross Ice Shelf Proj.)  
 UNIVERSITY OF NEW HAMPSHIRE DURHAM, NH (LAVOIE)  
 UNIVERSITY OF RHODE ISLAND Narragansett RI (Pell Marine Sci. Lib.)  
 UNIVERSITY OF SO. CALIFORNIA Univ So, Calif  
 UNIVERSITY OF TEXAS Inst. Marine Sci (Library), Port Arkansas TX



UNIVERSITY OF TEXAS AT AUSTIN Austin TX (R. Olson)  
 UNIVERSITY OF WASHINGTON Seattle WA (M. Sherif); SEATTLE, WA (APPLIED PHYSICS LAB);  
 SEATTLE, WA (OCEAN ENG RSCH LAB, GRAY); SEATTLE, WA (PACIFIC MARINE ENVIRON.  
 LAB., HALPERN); Seattle WA (E. Linger); Seattle, WA Transportation, Construction & Geom. Div  
 VIRGINIA INST. OF MARINE SCI. Gloucester Point VA (Library)  
 WOODS HOLE OCEANOGRAPHIC INST. Doc Lib LO-206, Woods Hole MA  
 ALFRED A. YEE & ASSOC. Librarian, Honolulu, HI  
 AMETEK Offshore Res. & Engr Div  
 ARCAIR CO. D. Young, Lancaster OH  
 ATLANTIC RICHFIELD CO. DALLAS, TX (SMITH)  
 BATTELLE-COLUMBUS LABS (D. Hackman) Columbus, OH  
 BECHTEL CORP. SAN FRANCISCO, CA (PHELPS)  
 BETHLEHEM STEEL CO. Dismuke, Bethlehem, PA  
 BRAND INDUS SERV INC. J. Buchler, Hacienda Heights CA  
 BRITISH EMBASSY M A Wilkins (Sci & Tech Dept) Washington, DC  
 BROWN & ROOT Houston TX (D. Ward)  
 CHEVRON OIL FIELD RESEARCH CO. LA HABRA, CA (BROOKS)  
 CICB O'Rourke  
 COLUMBIA GULF TRANSMISSION CO. HOUSTON, TX (ENG. LIB.)  
 CONCRETE TECHNOLOGY CORP. TACOMA, WA (ANDERSON)  
 CONTINENTAL OIL CO O. Maxson, Ponca City, OK  
 DESIGN SERVICES Beck, Ventura, CA  
 DILLINGHAM PRECAST F. McHale, Honolulu HI  
 DRAVO CORP Pittsburgh PA (Wright)  
 EVALUATION ASSOC. INC KING OF PRUSSIA, PA (FEDELE)  
 EXXON PRODUCTION RESEARCH CO Houston, TX (Chao)  
 FURGO INC. Library, Houston, TX  
 GEOTECHNICAL ENGINEERS INC. Winchester, MA (Paulding)  
 GOULD INC. Tech Lib, Ches Instru Div Glen Burnie MD  
 GRUMMAN AEROSPACE CORP. Bethpage NY (Tech. Info. Ctr)  
 HALEY & ALDRICH, INC. Cambridge MA (Aldrich, Jr.)  
 NUSC DET Library, Newport, RI  
 LAMONT-DOHERTY GEOLOGICAL OBSERVATORY Palisades NY (McCoy)  
 LIN OFFSHORE ENGRG P. Chow, San Francisco CA  
 LINEFAST CORP (J. DiMartino) Holbrook, NY  
 LOCKHEED MISSILES & SPACE CO. INC. L. Trimble, Sunnyvale CA  
 MARATHON OIL CO Houston TX  
 MARINE CONCRETE STRUCTURES INC. MEFAIRIE, LA (INGRAHAM)  
 MEDERMOTT & CO. Diving Division, Harvey, LA  
 MOBIL R & D CORP Manager, Offshore Engineering, Dallas, TX  
 MOFFATT & NICHOL ENGINEERS (R. Palmer) Long Beach, CA  
 EDWARD K. NODA & ASSOC Honolulu, HI  
 NEWPORT NEWS SHIPBLDG & DRYDOCK CO. Newport News VA (Tech. Lib.)  
 OPPENHEIM Los Angeles, CA  
 PACIFIC MARINE TECHNOLOGY (M. Wagner) Duvall, WA  
 PORTLAND CEMENT ASSOC. SKOKIE, IL (CORLEY; SKOKIE, IL (KLIEGER); Skokie IL (Rsch & Dev  
 Lab, Lib.)  
 R J BROWN ASSOC (R. Perera), Houston, TX  
 RAYMOND INTERNATIONAL INC. E Colle Soil Tech Dept, Pennsauken, NJ; J. Welsh Soiltech Dept,  
 Pennsauken, NJ  
 ROHR IND. INC (D. Buchanan) Chula Vista, CA  
 SANDIA LABORATORIES Library Div., Livermore CA; Seabed Progress Div 4536 (D. Talbert) Albuquerque  
 NM  
 SCHUPACK ASSOC SO. NORWALK, CT (SCHUPACK)  
 SEATECH CORP. MIAMI, FL (PERONI)  
 SHANNON & WILLSON INC. Librarian Seattle, WA  
 SHELL DEVELOPMENT CO. Houston TX (C. Sellars Jr.); Houston TX (E. Doyle)  
 SHELL OIL CO. HOUSTON, TX (MARSHALL); I. Boaz, Houston TX  
 TIDEWATER CONSTR. CO Norfolk VA (Fowler)  
 UNITED KINGDOM LNO, USA Meradcom, Fort Belvoir, VA  
 WESTINGHOUSE ELECTRIC CORP. Annapolis MD (Oceanic Div Lib, Bryan)  
 WESTINSTRUCORP Egerton, Ventura, CA  
 WISS, JANNEY, ELSTNER, & ASSOC Northbrook, IL (D.W. Pfeifer)  
 WM CLAPP LABS - BATTELLE DUXBURY, MA (LIBRARY)

WOODWARD-CLYDE CONSULTANTS Library, West. Reg., Walnut Creek, CA: PLYMOUTH MEETING  
PA (CROSS, III)  
BARA, JOHN P. Lakewood, CO  
BARTZ, J Santa Barbara, CA  
BULLOCK La Canada  
F. HEUZE Alamo, CA  
GERWICK, BEN C. JR San Francisco, CA  
LAYTON Redmond, WA  
OSBORN, JAS. H. Ventura, CA  
PAULI Silver Spring, MD  
R.F. BESIER Old Saybrook CT  
BROWN & CALDWELL Saunders, E.M./Oakland, CA

## INSTRUCTIONS

The Naval Civil Engineering Laboratory has revised its primary distribution lists. The bottom of the mailing label has several numbers listed. These numbers correspond to numbers assigned to the list of Subject Categories. Numbers on the label corresponding to those on the list indicate the subject category and type of documents you are presently receiving. If you are satisfied, throw this card away (or file it for later reference).

If you want to change what you are presently receiving:

- Delete — mark off number on bottom of label.
- Add — circle number on list.
- Remove my name from all your lists — check box on list.
- Change my address — line out incorrect line and write in correction (ATTACH MAILING LABEL).
- Number of copies should be entered after the title of the subject categories you select.

Fold on line below and drop in the mail.

Note: Numbers on label but not listed on questionnaire are for NCEL use only, please ignore them.

Fold on line and staple.

### DEPARTMENT OF THE NAVY

NAVAL CIVIL ENGINEERING LABORATORY  
PORT HUENEME, CALIFORNIA 93043

#### OFFICIAL BUSINESS

PENALTY FOR PRIVATE USE, \$300  
1 IND-NCEL-2700/4 (REV. 12-73)  
0930-LL-L70-0044

POSTAGE AND FEES PAID  
DEPARTMENT OF THE NAVY  
DOD-316



Commanding Officer  
Code L14  
Naval Civil Engineering Laboratory  
Port Hueneme, California 93043

## DISTRIBUTION QUESTIONNAIRE

The Naval Civil Engineering Laboratory is revising its primary distribution lists.

### SUBJECT CATEGORIES

- 1 **SHORE FACILITIES**
- 2 Construction methods and materials (including corrosion control, coatings)
- 3 Waterfront structures (maintenance/deterioration control)
- 4 Utilities (including power conditioning)
- 5 Explosives safety
- 6 Construction equipment and machinery
- 7 Fire prevention and control
- 8 Antenna technology
- 9 Structural analysis and design (including numerical and computer techniques)
- 10 Protective construction (including hardened shelters, shock and vibration studies)
- 11 Soil/rock mechanics
- 13 BEQ
- 14 Airfields and pavements
- 15 **ADVANCED BASE AND AMPHIBIOUS FACILITIES**
- 16 Base facilities (including shelters, power generation, water supplies)
- 17 Expedient roads/airfields/bridges
- 18 Amphibious operations (including breakwaters, wave forces)
- 19 Over-the-Beach operations (including containerization, materiel transfer, lighterage and cranes)
- 20 POL storage, transfer and distribution
- 24 **POLAR ENGINEERING**
- 24 Same as Advanced Base and Amphibious Facilities, except limited to cold-region environments
- 28 **ENERGY/POWER GENERATION**
- 29 Thermal conservation (thermal engineering of buildings, HVAC systems, energy loss measurement, power generation)
- 30 Controls and electrical conservation (electrical systems, energy monitoring and control systems)
- 31 Fuel flexibility (liquid fuels, coal utilization, energy from solid waste)
- 32 Alternate energy source (geothermal power, photovoltaic power systems, solar systems, wind systems, energy storage systems)
- 33 Site data and systems integration (energy resource data, energy consumption data, integrating energy systems)
- 34 **ENVIRONMENTAL PROTECTION**
- 35 Solid waste management
- 36 Hazardous/toxic materials management
- 37 Wastewater management and sanitary engineering
- 38 Oil pollution removal and recovery
- 39 Air pollution
- 40 Noise abatement
- 44 **OCEAN ENGINEERING**
- 45 Seafloor soils and foundations
- 46 Seafloor construction systems and operations (including diver and manipulator tools)
- 47 Undersea structures and materials
- 48 Anchors and moorings
- 49 Undersea power systems, electromechanical cables, and connectors
- 50 Pressure vessel facilities
- 51 Physical environment (including site surveying)
- 52 Ocean-based concrete structures
- 53 Hyperbaric chambers
- 54 Undersea cable dynamics

### TYPES OF DOCUMENTS

- |                                     |  |                         |                                |
|-------------------------------------|--|-------------------------|--------------------------------|
| 85 Techdata Sheets                  | 86 Technical Reports and Technical Notes | 82 NCEL Guide & Updates | <input type="checkbox"/> None— |
| 83 Table of Contents & Index to TDS |  | 91 Physical Security    | remove my name                 |



PLEASE HELP US PUT THE ZIP IN YOUR  
MAIL! ADD YOUR FOUR NEW ZIP DIGITS  
TO YOUR LABEL (OR FACSIMILE),  
STAPLE INSIDE THIS SELF-MAILER, AND  
RETURN TO US.

(fold here)

**DEPARTMENT OF THE NAVY**

NAVAL CIVIL ENGINEERING LABORATORY  
PORT HUENEME, CALIFORNIA 93043-5003

**OFFICIAL BUSINESS**

PENALTY FOR PRIVATE USE, \$300

1 IND-NCEL 2700/4 (REV. 12-73)

0930-LL-L70-0044

POSTAGE AND FEES PAID  
DEPARTMENT OF THE NAVY  
DOD-316



Commanding Officer  
Code L14  
Naval Civil Engineering Laboratory  
Port Hueneme, California 93043-5003



W H O I  
DOCUMENT  
COLLECTION

DEPARTMENT OF THE NAVY

NAVAL CIVIL ENGINEERING LABORATORY  
PORT HUENEME, CALIFORNIA 93043

OFFICIAL BUSINESS  
PENALTY FOR PRIVATE USE, \$300

POSTAGE AND FEES PAID  
DEPARTMENT OF THE NAVY  
DOD-316



823.001 - 294

1

Document Library LO-206  
Woods Hole Oceanographic Institution  
Woods Hole, MA 02543

46,47,48,49,52,79,82,86